ADA

TESTING OF PROTOTYPE CONDUIT

INTERIM REPORT
TFLRF No. 401

by

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U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV09C0100 (WD0007)

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14. ABSTRACT

A prototype light weight, lay flat, high working pressure hose capable of flowing 800 gallons per minute has been evaluated through a number of screening tests to identify its potential for augmenting or replacing IPDS aluminum tubing. This new hose exhibits very low elongation and twist and exhibits a working pressure of 650 psi based on a 3:1 safety factor. The next recommended step is for the hose to undergo some product improvements and then be fully evaluated under hot and cold weather environments.

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EXECUTIVE SUMMARY

Problems and Objectives

A rapidly deployable hose system has been sought to augment the IPDS by significantly reducing the time required to deploy a liquid transfer line. This hose system must retain the general flow and pressure requirements of IPDS 6-inch diameter aluminum tubing, but also provide a lay flat hose that can be rolled up on a spool system and be deployed from the spool system in such a manner to greatly reduce the deployment and retrieval time. To date, only one manufacturer has produced a hose that has come close to being compatible with the IPDS. However, this hose experienced excessive elongation and was expected to be rated at approximately 550 psi working pressure, which is less than the 740 psi working pressure of the IPDS. Snap-tite Hose, Inc. (a Pennsylvania Corporation) developed a new technology hose circa 2008 that may meet the requirements for a rapidly deployable hose and overcome notable problems experienced with other hose systems. As such TARDEC initiated a test program to screen the basic performance characteristics of the Snap-tite hose to evaluate the technology readiness exhibited by the hose. The objective of this program is to conduct independent screening tests on Snap-tite's prototype conduit to include but not limited to fuel compatibility, burst pressurization, twist and elongation, and cycling tests to represent employments and retrieval cycles as might be expected with field equipment. Flow performance is to be estimated through hydraulic analysis.

Importance of Project

The Army, at the moment, has only one source for a moderately successful high pressure lay flat hose system. This project has identified many positive attributes of the Snap-tite hose that make it a viable candidate for further and needed development such that at some future date it can augment or replace the IPDS piping. Therefore, potentially two sources of high pressure, lay flat, six-inch diameter hoses are available.

Technical Approach

A series of screening tests were identified to answer critical questions relating to the advisability of continuing the development of the Snap-tite high pressure, lay flat, high volume flow hose. A successful test would show that the hose is capable of meeting similar pressure and flow performance of the IPDS piping and be capable of meeting deployment and retrieval requirements, and identify areas of concern where hose improvements would be beneficial. Therefore standardized and custom tests were conducted to measure burst pressure, twist and elongation of the hose, hose toughness due to repeated flexing, fuel compatibility, and analysis was conducted to estimate pressure drop characteristics.

Accomplishments

Based on burst testing results of two sections of new hose, and after applying a 3:1 safety factor, the hose working pressure would be 650 psi. Based on burst testing results of two sections of the new hose that experienced multiple flexing and pressurization cycles, and after applying a 3:1 safety factor, the hose working pressure would be 515 psi. The final working pressure rating will need to take into account both burst pressure when new and burst pressure after cycle testing and, therefore, will be less than the 650 psi. Hose elongation was measured to be 0.97 % at a working pressure of 650 psi and the twist under the same pressure was measured to be 0.43 deg per foot of length of the hose. The weight of the hose is approximately 1.18 pounds per foot. A small variation in tensile strength was noted due to soaking of hose samples in Diesel fuel (Grade 2) or soaking of samples in JP-8 for 216 hours, but a larger number of specimens need to be tested to draw conclusions on possible strength reductions. Pressure drop estimates based on surface roughness measurements show that the hose will drop pressure on the order of 285 feet of fluid per mile at a flow of 800 gallons per minute and a drop of 165 feet of fluid per mile at 600 gallons per minute. The calculated pressure drop of 285 feet of fluid compares very favorably with the 250 feet of fluid as originally specified for RIFTS developmental hose; however, the pressure drop of IPDS piping is 186 feet of fluid at 800 gallons per minute.

Military Impact

As the military moves forward to explore rapidly deployable and retrievable hose systems such as the RIFTS concept, the Snap-tite hose offers another potential source of high pressure, lay flat, light weight, and high flow volume hose based on the screening tests conducted in this study. The Snap-tite hose when compared to IPDS aluminum tubing has a lower working pressure when new (640 psi) that can be expected to degrade with use (515 after cycle testing). The final rated working pressure of this hose, although undetermined at this time, will need to take into account degradation from use. IPDS pipe is rated at 740 psi working pressure. The *estimated* hose pressure drop is approximately 50% greater than IPDS aluminum tubing. These differences will require the system to be operated at a lower working pressure with pump stations placed closer together when compared to the IPDS. But to be fair, the lighter weight Snap-tite hose compares very well with one only known alternative hose product in terms of pressure and flow performance, and it has excellent elongation characteristics of less than 1%.

There are some remaining design issues to be addressed with the Snap-tite hose, but they appear to be well within a normal design improvement process. Issues of importance to address are (1) a lower weight and shorter length hose coupling, (2) the development of a smoother interior wall of uniform thickness, (3) determine the feasibility and affordability of achieving 700 psi working pressure for a layflat hose, and (4) when appropriate, a full qualification program should be performed under hot and cold weather conditions.

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ACRONYMS AND ABBREVIATIONS

°C	Degrees Centigrade
°F	Degrees Fahrenheit
ASTM	American Society for Testing Materials
cSt	Centistokes
Gal/hr *or* gph	Gallons per Hour
GPM	Gallons per Minute
IPDS	Inland Piping and Distribution System
JP-8	Jet Propulsion Fuel 8
Kg	Kilogram
kW	Kilowatt
l	liter(s)
M^3	Cubic Meter(s)
MEP	Mobile Electric Power
mm^2	Millimeter(s) Squared
mmHg	Millimeter(s) Mercury
psi	Pounds per Square Inch
PSIG	Pounds per Square Inch Gauge
RDECOM	Research Development and Engineering Command
rms	Root-mean-square
S	Second
SAE	Society of Automotive Engineers
SWRI®	SOUTHWEST RESEARCH INSTITUTE®
TACOM	Tank Automotive Command
TARDEC	Tank Automotive Research and Development Command
TFLRF	TARDEC Fuels and Lubricants Research Facility
vol	Volume

1.0 INTRODUCTION AND OBJECTIVE

Snap-tite, Inc. has developed a high-pressure six-inch diameter lay flat hose. Snap-tite has conducted burst pressure, elongation and twist tests to demonstrate that the new technology hose exhibits desirable performance characteristics for applications of petroleum and water distribution. This hose technology may be an alternative rapidly deployable hose to supplement or replace IPDS hard aluminum tubing. With full concurrence from Snap-tite, TARDEC has sought independent testing of the conduit to verify the initial test results and to provide other independent review. Hence, a series of screening tests have been identified to determine basic performance characteristics of the hose. Based on results of these screening tests, TARDEC will determine if more detailed tests are warranted.

The objective of this program is to conduct independent screening tests on Snap-tite's prototype conduit to include but not limited to fuel compatibility, burst pressurization, twist and elongation, and cycling tests to represent employments and retrieval cycles as might be expected with field equipment. Flow performance is to be estimated through hydraulic analysis. The purpose of these screening tests and analysis is to verify basic design features of the hose and to provide information on the level of technology readiness of the hose.

2.0 HOSE AND END FITTING DESCRIPTION

2.1 Hose Description

The Snap-tite, high-pressure conduit is a lightweight, lay-flat hose similar in appearance to a standard MIL-PRF-370 hose. The end fittings are re-attachable and consist of a tailpiece and two-piece split clamp. Eight screws close the clamp. The end connection is a standard IPDS single groove end fitting. Figure 2.1 shows a hose sample with fittings on each end.

Figure 2.1 – Snap-Tite High Pressure Conduit

The construction of the Snap-tite conduit was reported to be a through-the-weave extrusion (polyurethane) type of hose with a jacket of twill weave of proprietary yarn. Figure 2.2 shows the exposed jacket (extruded material removed to show the jacket).

Figure 2.2 – Conduit Jacket and Cover

Figure 2.2 also shows the texture created in the cover that is a result of the weave pattern. Figure 2.3 shows the similar texture of the liner including what is sometimes referred to as the bias angle of the weave. This pattern may influence the flow performance of the conduit by creating additional pressure drop due to a swirling flow (discussed in Section 7.0).

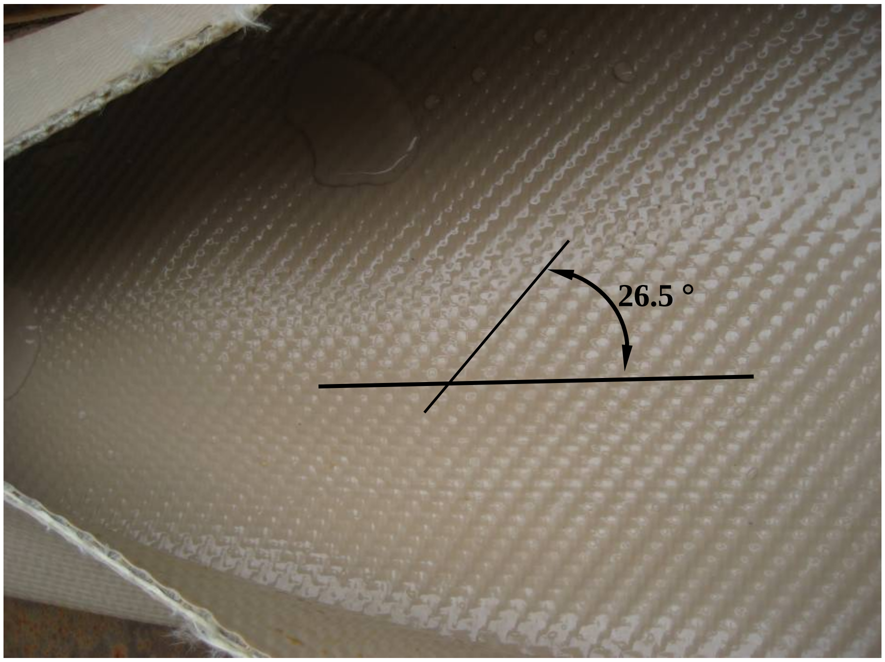


Figure 2.3 – Surface of Conduit Liner

The conduit was light enough to handle and roll by hand and could easily be cut with a knife. The end fittings were simple to install. On his first try, a Southwest Research Institute technician required approximately 15 minutes to mount a single end fitting to the house, while a Snap-tite representative supervised the technician. The measured weight of the hose is 1.18 lbs/ft.

2.2 End Fitting Description

Two hose samples were received with an end fitting installed at each end of the hose (for a total of four couplings). No design or assembly drawings of the couplings were furnished. The end fittings are constructed of aluminum and consist of a two-piece split clamp, a two-piece inner sleeve, and a tailpiece. The split clamp halves are held fast with eight screws that are threaded orthogonally into a solid steel round rod. *It is observed that several design modifications would* *enhance the quality and performance of the coupling.* (1) The coupling in its present form is relatively long at 11 inches. Therefore, when two couplings are locked together, a hose connection length of 22 inches is formed. This length may pose problems when winding the hose on a spool system. (2) Numerous sharp edges exist and they should be chamfered to protect from cutting o-rings and to reduce crack initiation sites that may lead to fatigue problems. (3) The "inside of the hose" end of the tailpiece should be chamfered to reduce flow losses caused by sharp edges. Figure 2.4 through Figure 2.8 show photographs of the end fittings and their assembly.

Figure 2.4 – Assembled End Fitting

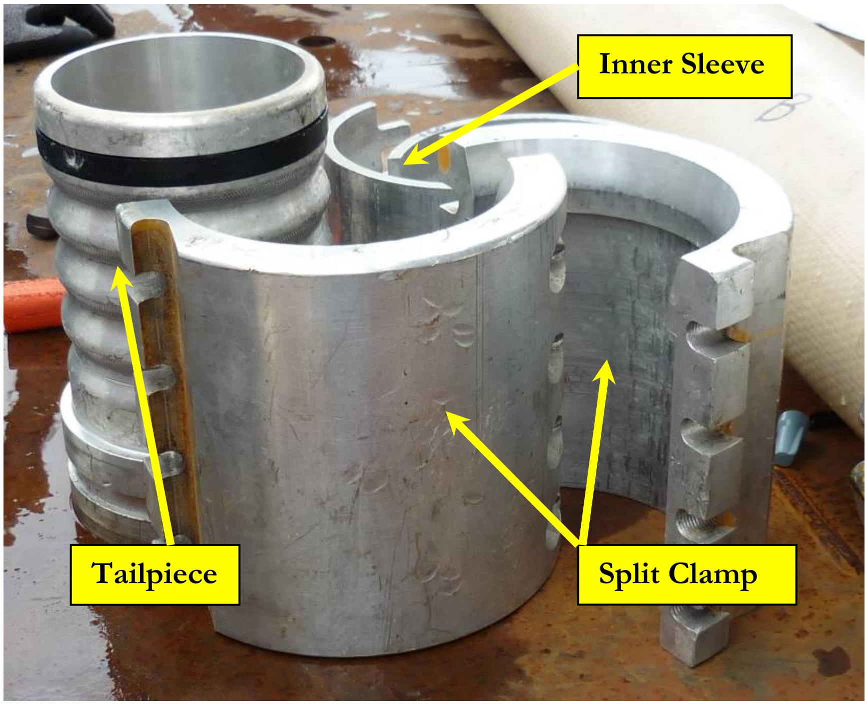


Figure 2.5 – Disassembled Components of End Fitting

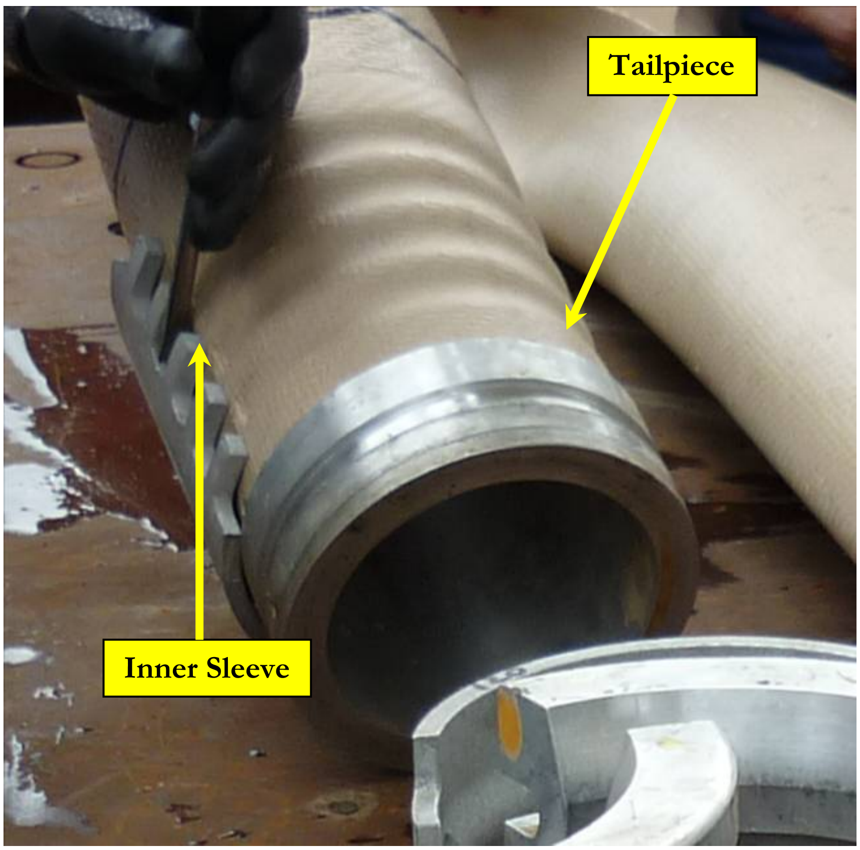


Figure 2.6 – Tailpiece Inserted in Hose and Inner Sleeve Being Installed

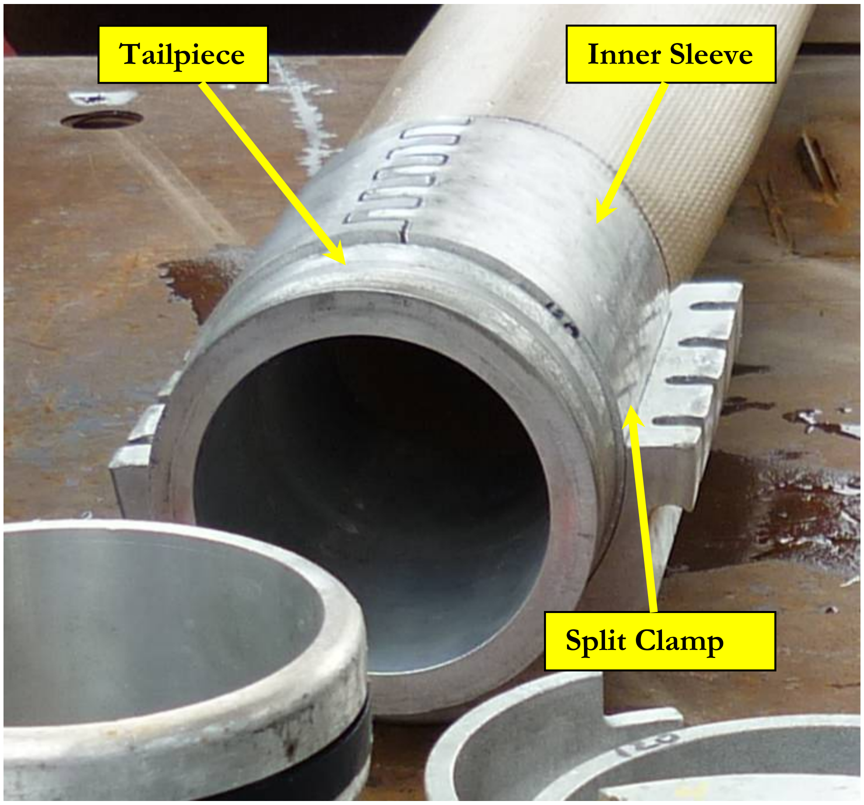


Figure 2.7 – Inner Sleeve Fully Installed and Split Clamp Being Installed

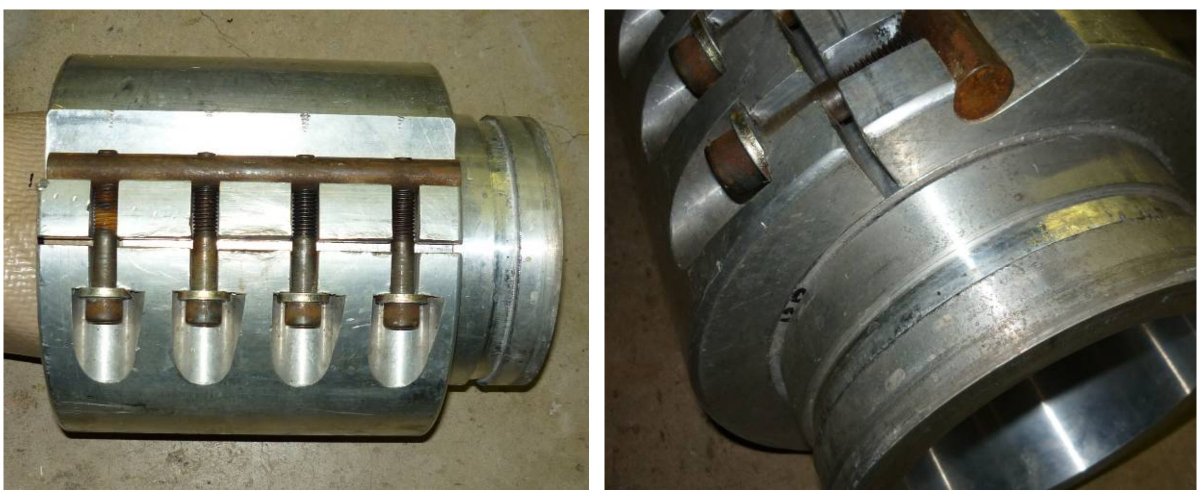


Figure 2.8 – Screws Fastening Split Clamp Together – Used on Both Sides of End Fitting

The assembly procedure involves first sliding the hose over the tailpiece until it butts against a collar on the tailpiece. After the tailpiece is fully seated into the hose, the inner sleeve is lightly hammered into position around the portion of the tailpiece covered by the hose. Finally, the split clamp is installed around the inner sleeve and held together with two screw assemblies. The inner sleeve and the split clamp butt against the edge of the hose stop on the tailpiece, so no measurements or gages are required to locate the clamp in the correct position over the tailpiece. The screw assemblies are alternately tightened so that the gaps between the halves of the split clamp are even and symmetric. The screws are final-tightened to a prescribed torque value.

2.3 Initial Inspection

Five individual hose samples were received for testing. Upon receiving the test samples, each test sample was inspected and identified with a Test Sample Identifier. The Test Sample Identifier was a letter from A to E.

Preliminary arrangements were made with Snap-tite to receive four hose that were 15 feet long and one hose that was 100 feet long. Upon receiving the hoses, their lengths were measured and are presented in Table 2.1. Note that some of these measurements were made with end fittings installed and some were not. Snap-tite shipped two of the hoses (hoses B and C) with end fittings installed at the factory. Photographs of the hoses, as they were received from Snap-tite, are shown in Figure 2.9 and Figure 2.10.

Table 2.1 – Lengths of Hose Samples at Initial Inspection

Hose Sample	Length (feet)	Notes
A	100.00	Approximate length (hose was not measured at time of inspection).
B	12.96	Measured with end fittings installed
C	17.62	Measured with end fittings installed
D	14.87	Measured without end fittings installed
E	14.25	Measured without end fittings installed
All hoses had a nominal diameter of 6 inches.		

Figure 2.9 – Hoses, As Shipped from Snap-tite

Figure 2.10 – Four Short Length Hoses Laid Flat

During inspection of the hose samples, there were no major defects or damage noted for any of the hose samples. There were a couple of minor flaws noted on the outer surface of some of the samples. Primarily there were two types of flaws found. One flaw consisted of small dimples of extra material present on the outside of the hose, as shown in Figure 2.11. The other flaw consisted of smooth areas on the outer texturing of the hose, as shown in Figure 2.12. None of these flaws appeared to be significant and did not appear like they would affect the performance of the hoses. No actions were taken to repair the flaws or to replace the hoses.

Figure 2.11 – Example of Surface Defect Noted During Inspection

Figure 2.12 – Another Example of Surface Defect Noted During Inspection

3.0 BURST TESTS

Screening tests have been conducted to measure the hose burst pressure, hose elongation and twist at working pressure, and tests have been conducted to determine potential degradation due to flexing when rolled over a small diameter roller for repeated cycles. In this section, burst testing is discussed.

Burst tests were used to determine the ultimate pressure load the hoses can sustain and to determine the working pressure of the conduit based on a 3-to-1 safety factor. Two of the nominal 15-foot hoses were burst tested before undergoing any other kind of testing. Two other 15-foot hoses were burst tested after they were subjected to cyclic testing. Even though two of the burst tests were performed after cyclic testing, the results of those burst tests will be discussed in this section.

3.1 Burst Pressure

The essential procedures of the burst test are presented below in Table 3.1.

Table 3.1 – Burst Test Procedure

Step No.	Description
1	End Plugs should be installed on both ends of the conduit using IPDS couplings to attach them to the conduit end fittings.
2	Set up the plumbing for the pump to pressurize the conduit.
3	Setup the Data Acquisition System (DAS) and check for proper operation, with a scan interval no greater than 1 Hz.
4	Visually inspect the conduit section and document the conduit's condition on the data sheet. The conduit should be supported by the PVC rollers along the length of the section.
5	Ensure that the conduit section is not twisted.
6	Photograph the test setup from multiple angles making sure at least one photo shows the entire test sample.
7	Attach the water inlet line, pressure transducer line, and thermocouples to the end plugs.
8	Fill the conduit with water and purge as much air as practical from the conduit (approximately 20 psi in hose).
9	Close the inlet and exit water lines.
10	With approximately 60 psi (city water pressure) in the hose, measure the length of the conduit length overall (LOA) and length of hose between collars (free length) with the measuring tape (document on data sheet).
11	Make sure that the video cameras are positioned correctly to record the burst.

Step No.	Description
12	Ensure that all personnel have cleared the area before proceeding and that proper means have been taken to warn/prevent bystanders from approaching testing facilities.
13	Record the filename on the data sheet and make sure that there is adequate media to video record the burst test.
14	Activate DAS and video recorder.
15	Turn on the pump and check the DAS system for proper operation.
16	Increase pressure on the conduit at a continuous rate. The target rate of increase is 1000 psig per minute.
17	Allow the conduit section to burst.
18	Record the pressure at which the conduit burst.
19	Turn off the pump.
20	De-activate the DAS and video recorder.
21	Ensure the video file/tape is labeled.
22	Visually examine the conduit and take photographic records. Also, note the condition of the conduit on the data sheet.
23	Record the date and burst pressure on the conduit section with a paint pen

3.2 Burst Pressure Test Results

Hose Samples B and D were subjected to burst tests before undergoing any other kind of testing. Hose Samples C and E were burst tested after they were subjected to cyclic testing. The results of the burst tests are presented in Table 3.2.

Table 3.2 – Summary of Burst Test Results

Sample	Length (ft.)[1]	Burst Pressure (psig)	Failure Mode	Cycled Tested Before Burst Test
B	13.08	1966	Pin holes in liner, no apparent yarn break	No
C	17.80	1467	Large axial tear, 65+ weft yarns broken	Yes
D	14.92	1896	Small hole, 1-2 weft yarns broken/protruding	No
E	14.31	1621	Small hole, 2 weft yarns broken	Yes

[1]Measured from outer edges of end fittings with hose sample at 60 – 65 psig

Hose samples B and D had an average burst pressure of 1931 psig, with a range of 70 psig between the two bursts. Using the bust pressure of 1931 psig, the working pressure of the hoses was calculated to be 644 psig. For practicality, the working pressure was rounded to 650 psig. Hose samples C and E had an average burst pressure of 1544 psig, with a range of 154 psig. The average burst pressure of the hoses which had previously undergone cyclic testing was 387 psig lower than the average burst pressure of the hoses with no previous testing. It will be discussed in the cyclic testing section, but is worthwhile to note that during the cyclic testing a short section of the hose was pulled around a 3-inch radius bend and a 36-inch radius bend. The section of hose which is exposed to the smaller 3-inch bend radius is exposed to the most severe portion of the cyclic test. In both of the burst tests that were performed on the hoses that had previously undergone cyclic tested hoses, the bursts occurred in the section of hose that was subjected to the 3-inch radius bend.

Figure 3.1 through Figure 3.9, show the setup of each hose sample as well as the respective failure. The pressure time-history graphs of the burst test data can be found in Appendix A and Engineering Data Sheets are found in Appendix B.

An interesting behavior was noted while setting up the initial burst test. While performing some checks it was noted that the end fittings "cocked" on the ends of the hose when the hose was pressurized. Closer inspection determined that slippage was not occurring between the hose and end fitting – circumferential lines that had been drawn on the OD of the hose at the inboard edges of the split clamps when the end fittings were installed remained at the inboard edges of the clamps (see Figure 3.2). During the course of the testing, it was noted that the end fittings would consistently become "cocked" to some degree on every hose. The "cocking" of the end fittings becomes evident at low pressures. Snap-tite personnel stated that they noted the same "cocking" behavior at their facility and is caused by the construction of the hose during the extrusion process and is not caused by the construction of the end fittings or an incorrectly assembled end fitting. The Snap-tite representatives stated that the "cocking" of the end fittings would not affect the test results. None of the test samples burst at the end fittings.

Figure 3.1 – Hose Sample B - Burst Test Setup

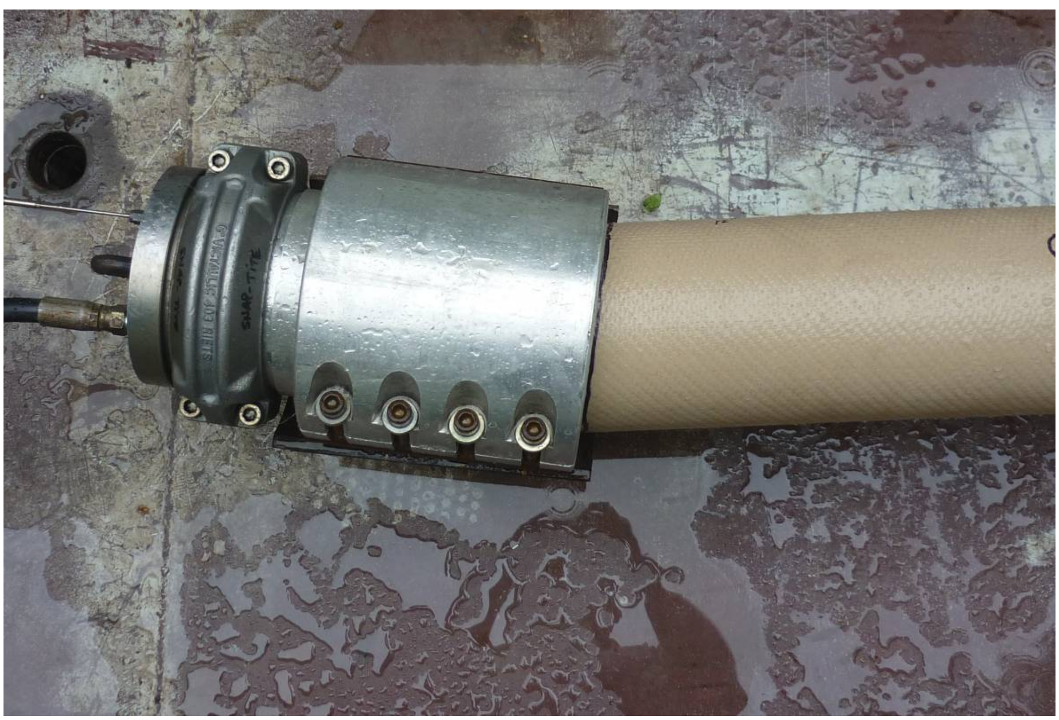


Figure 3.2 – Hose Sample B – “Cocked” End Fitting at 60 PSIG

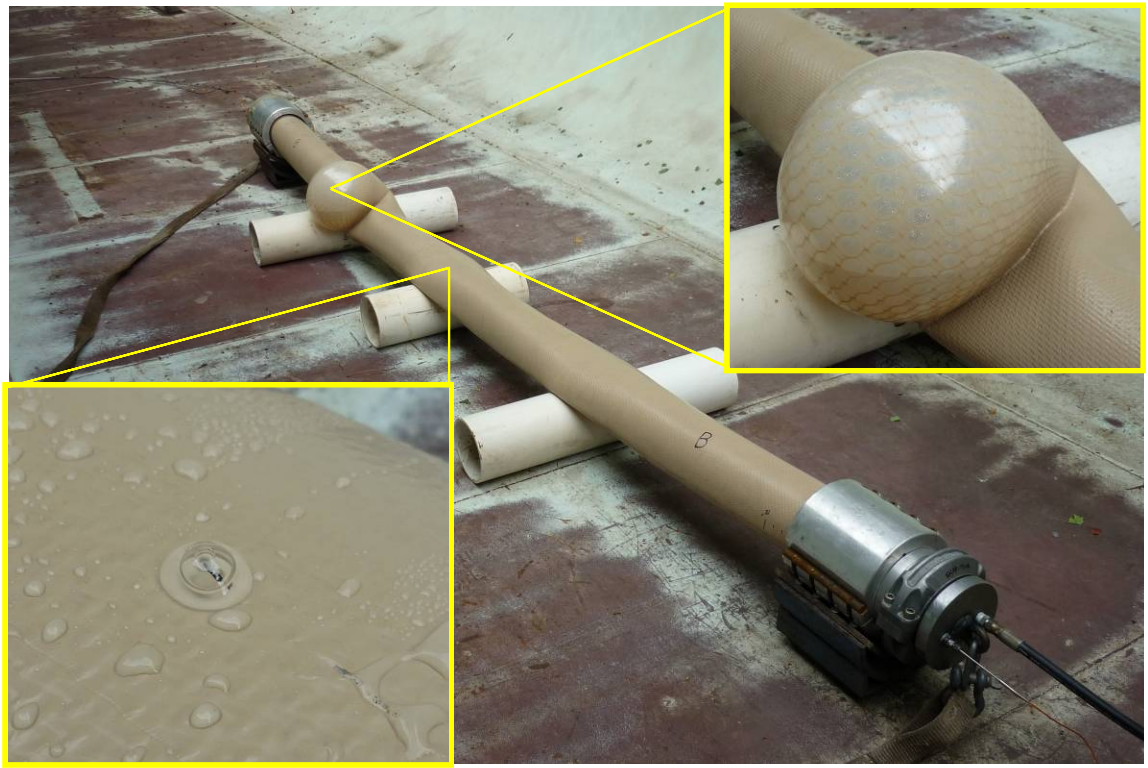


Figure 3.3 – Hose Sample B Failure

Figure 3.4 – Hose Sample C Burst Test Setup

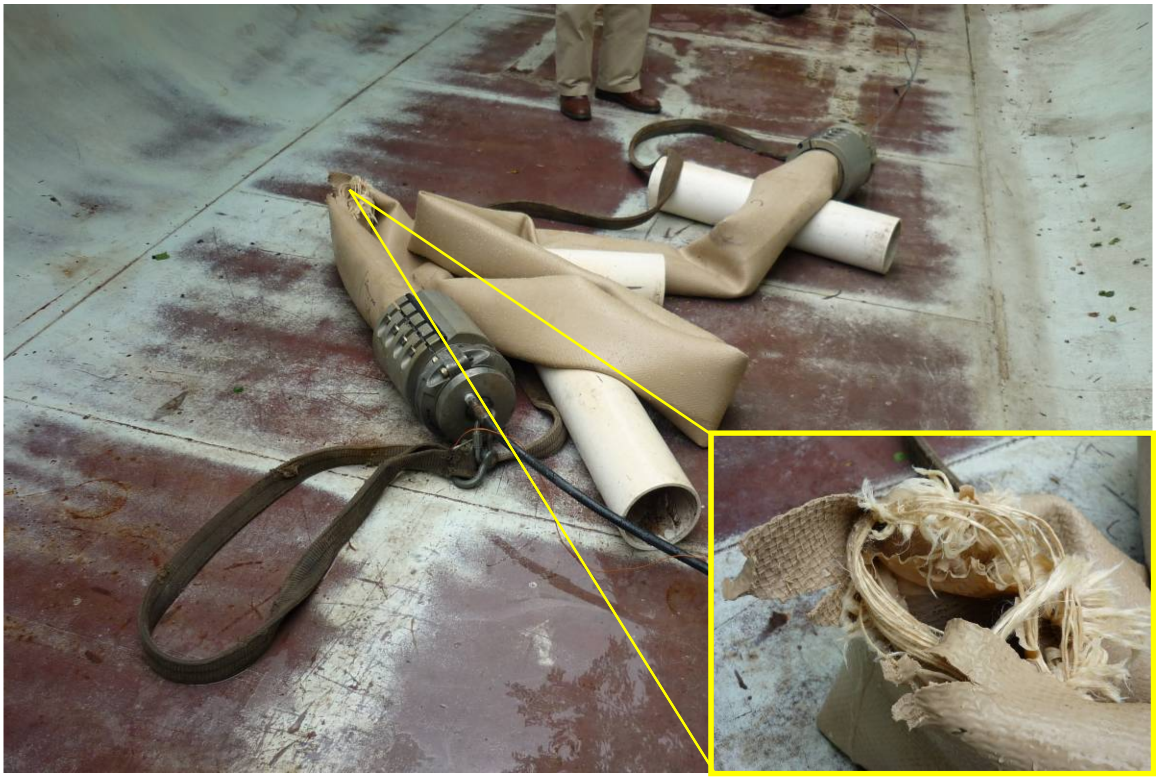


Figure 3.5 – Hose Sample C Failure

Figure 3.6 – Hose Sample D Burst Test Setup

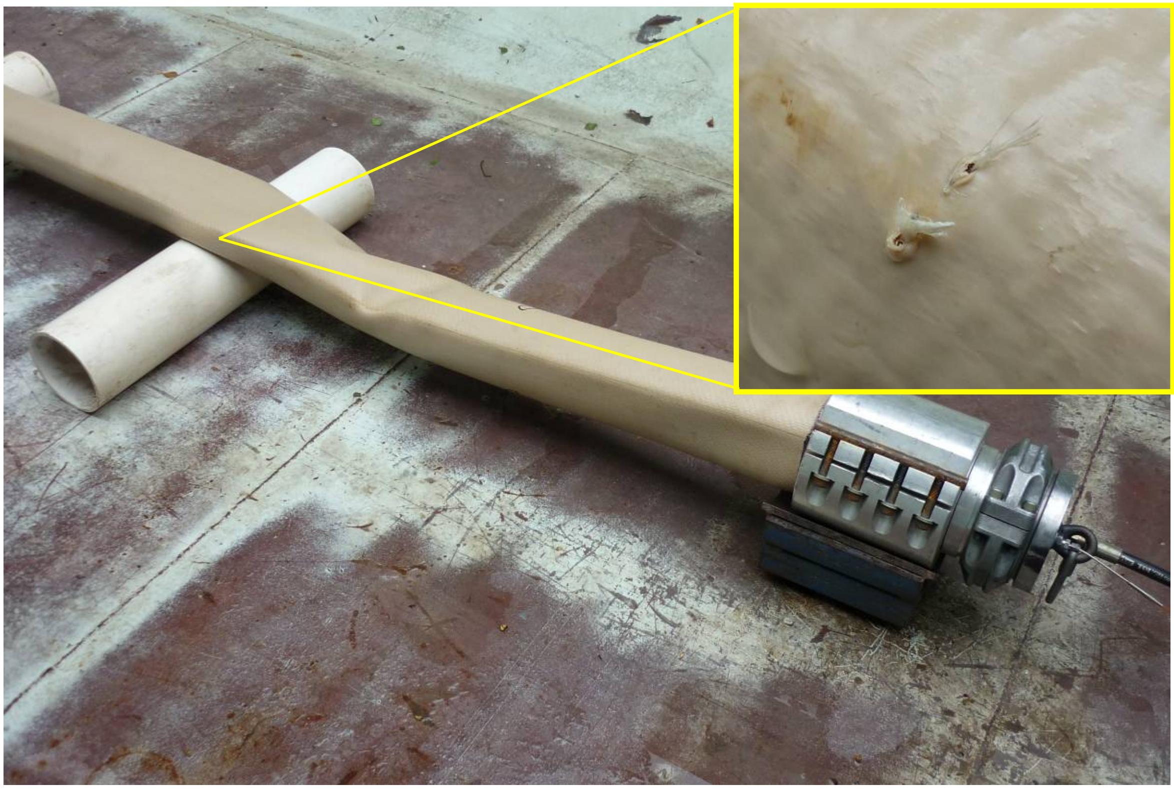


Figure 3.7 – Hose Sample D Failure

Figure 3.8 – Hose Sample E Burst Test Setup

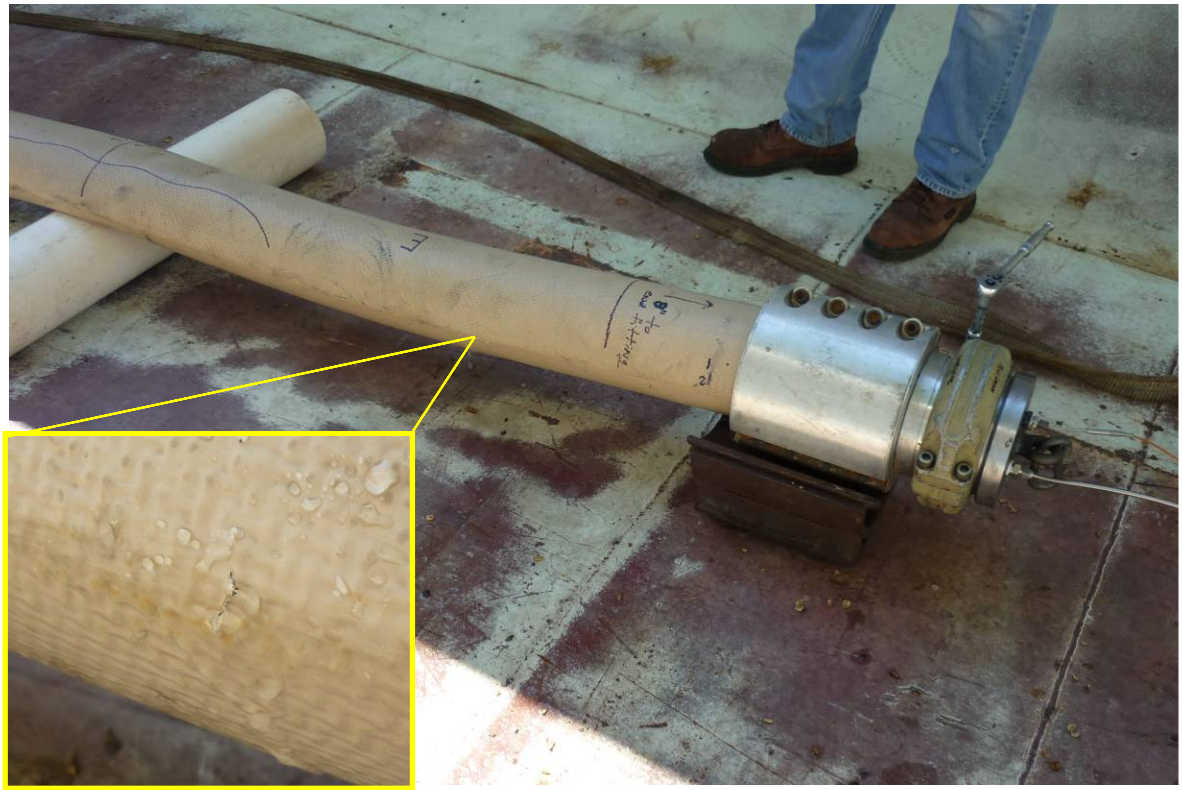


Figure 3.9 – Hose Sample E Failure

4.0 CYCLIC TESTS

Cyclic tests were used to simulate conditions that the actual conduit could experience during emplacement and retrieval in the field when the hose is wrapped and unwrapped on a spool during these events. Conduit sections were subjected to alternating bending around a 3-inch radius and a 36-inch radius, and pressurization cycles. For the pressurization cycles, a working pressure of 650 psig was used. Of the five hoses delivered by Snap-tite, two of the 15-foot hoses were cyclic tested.

4.1 Cyclic Test Procedure

The essential procedures of the burst test are presented below in Table 4.1.

Table 4.1 – Cyclic Test Procedure

Step No.	Description
1	End Plugs should be installed on both ends of the conduit using IPDS couplings to attach them to the conduit end fittings.
2	Measure the length of the conduit with the measuring tape (document on data sheet)
3	Ensure that the couplings are properly installed on each end of the conduit section.
4	Visually inspect the conduit section and document the conduit's condition on the data sheet.
Bending Cycles	
5	Thread the conduit into the Bend Cycle test fixture. If there is wording on only one side of the conduit, position the conduit section with the wording facing away from the 36" roller.
6	Attach the counterweight to the free end of the conduit section and attach the other end to the winch.
7	Mark the extreme positions of the hose for reference when performing the cyclic testing (8" from coupling – start of 3" radius, 49" from coupling – start of 36" radius).
8	Photograph the test setup from multiple angles making sure at least one photo shows the entire test sample.
9	Ensure that only the winch operator is in close proximity to the testing apparatus before proceeding and that proper means have been taken to warn/prevent bystanders from approaching testing facilities.
10	Commence cyclic testing and subject the conduit to 100 bending cycles. Indicate the completion of the bending cycles on the data sheet and include the date.
11	Remove the conduit from the bending apparatus and transfer the conduit to the pressure testing site.
Pressure Cycles	
12	End Plugs should be installed on both ends of the conduit using couplings to attach them to the conduit end fittings.
13	Set up the plumbing for the pump to pressurize the conduit.
14	Setup the Data Acquisition System (DAS) and check for proper operation, with a scan interval no greater than 1 Hz.
15	Visually inspect the conduit section and document the conduit's condition on the data sheet. The conduit should be supported by the PVC rollers along the length of the section.
16	Ensure that the conduit section is not twisted.
17	Attach the water inlet line, pressure transducer line, and the thermocouples to the end plugs.
18	Fill the conduit with water and purge as much air as practical from the conduit (approximately 20 psi in hose).
19	Close the inlet and exit water lines.
20	With approximately 60 psi (city water pressure) in the hose, measure the length of the conduit length overall (LOA) and length of hose between collars (free length) with the measuring tape (document on data sheet).
21	Make sure that the video cameras are positioned correctly to record the pressure testing and burst.
22	Ensure that all personnel have cleared the area before proceeding and that proper means have been taken to warn/prevent bystanders from approaching testing facilities.
23	Record the filename on the data sheet and make sure that there is adequate media to video record the cyclic test.
24	Activate DAS and video recorder.
25	Turn on the pump and check the DAS system for proper operation.
26	Pressurize the conduit to the Working Pressure (min) then back down to 10 psi (min) for a total of 20 pressure cycles. Indicate the completion of the pressure cycles on the data sheet and include the date.
27	After completing all 20 cycles, with approximately 10 psi in the hose, measure the length of the conduit length overall (LOA) and length of hose between collars (free length) with the measuring tape (document on data sheet).

4.2 Cyclic Test Results

Hose Samples C and E were subjected to cyclic testing. Both hose samples passed the bending tests without any visible damage or permanent deformations. Both hose samples passed the pressurization cycles without bursting or any signs of leaking. At the conclusion of the bending and pressurization cycles, the two hoses were burst tested.

Hose samples C and E had an average burst pressure of 1544 psig, with a range of 154 psig. The average burst pressure of the hoses which had undergone cyclic testing was 387 psig lower than the average burst pressure of the hoses with no previous testing. In both of the burst tests, the bursts occurred in the section of hose that was subjected to the 3-inch radius bend. Based on a very limited number of burst tests, it appears that some degradation of the hose structure is present due to flexing of the carcass; however, a greater number of burst tests would provide a stronger statistics base from which to draw conclusions.

As noted during the burst tests, the end fittings appeared “cocked” on the ends of the hose. The “cocking” of the end fittings was not evident during the bending cycle tests because the hose was not pressurized. The “cocking” of the end fittings was evident during the pressure cycle tests, but did not appear to affect the outcome of the tests.

Figure 4.1 through Figure 4.7 shows the setup use for cycle testing. The pressure time-history graphs of the pressure cycle data and the burst test data can be found in Appendix A.

Figure 4.1 – Cyclic Testing – Bending Test Fixture (View 1)

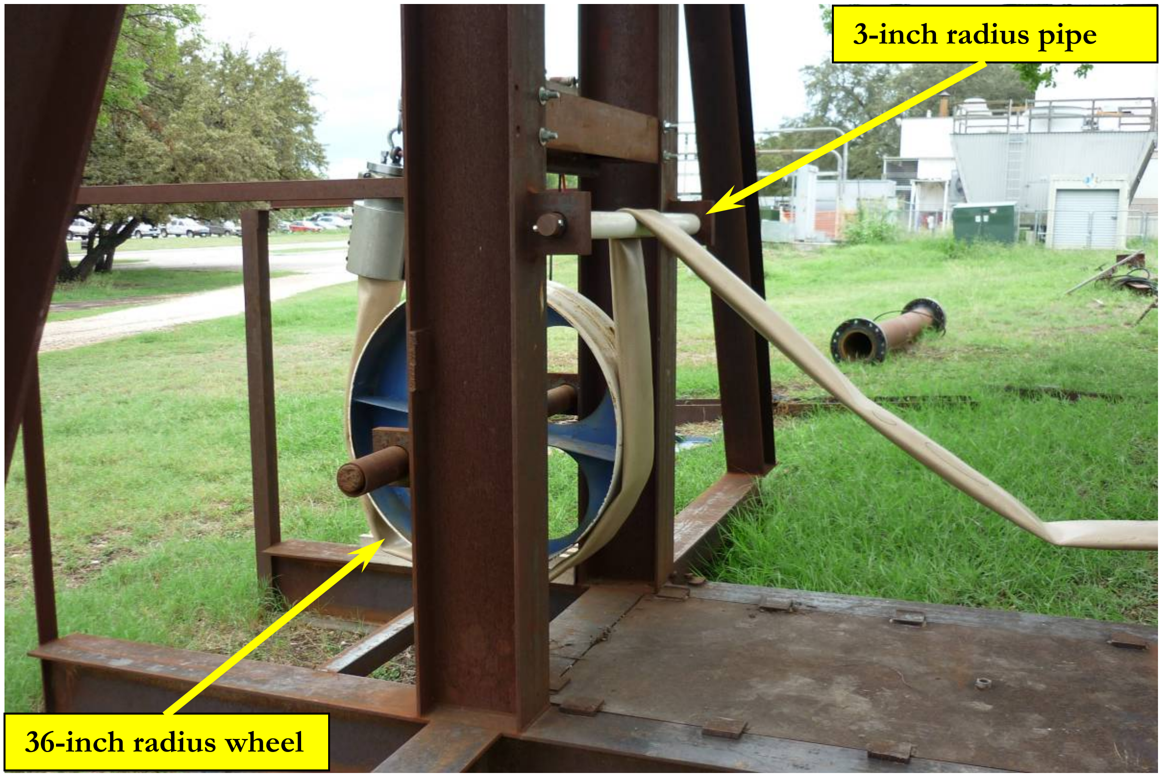


Figure 4.2 – Cyclic Testing – Bending Test Fixture (View 2)

Figure 4.3 – Cyclic Bend Testing of Hose Sample C (View 1)

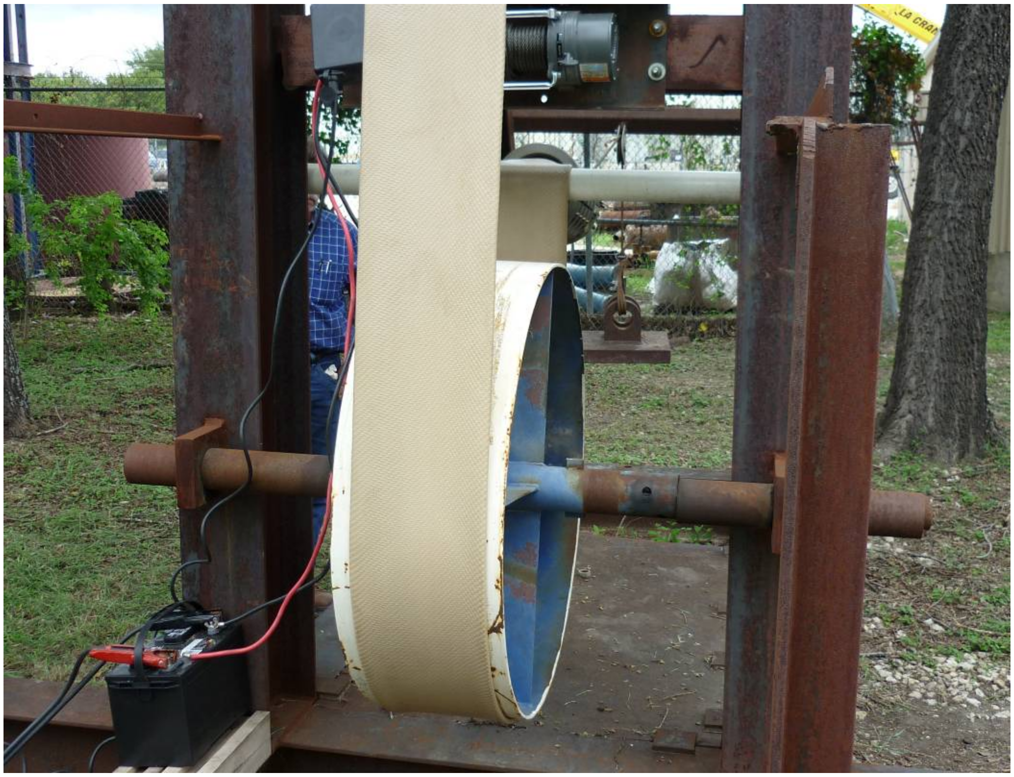


Figure 4.4 – Cyclic Bend Testing of Hose Sample C (View 2)

Figure 4.5 – Cyclic Pressurization Testing of Hose Sample C

Figure 4.6 – Cyclic Bend Testing of Hose Sample E

Figure 4.7 – Cyclic Pressurization Testing of Hose Sample E

5.0 ELONGATION AND TWIST TESTS

An elongation and twist test was used to determine the degree to which a 100-foot section of the conduit will elongate and twist when pressurized to working pressure (650 psig). Of the five hoses delivered by Snap-tite, only the single 100-foot hose was subjected to the twist and elongation test.

5.1 Elongation and Twist Test Procedure

The essential procedures of the elongation and twist test are presented below in Table 5.1.

Table 5.1 – Burst Test Procedure

Step No.	Description
1	Lay out the conduit in a straight line on relatively level ground.
2	End Plugs should be installed on both ends of the conduit using IPDS couplings to attach them to the conduit end fittings.
3	Set up the plumbing for the pump to pressurize the conduit.
4	Setup the Data Acquisition System (DAS) and check for proper operation, with a scan interval no greater than 1 Hz.
5	Visually inspect the conduit section and document the conduit's condition on the data sheet.
6	Ensure that the conduit section is not twisted.
7	Photograph the test setup from multiple angles making sure at least one photo shows the entire test sample.
8	Attach the water inlet line, pressure transducer line, and the thermocouples to the end plugs.
9	On the two End Plugs, mark lines to indicate the initial vertical position of the end plugs (at 12:00 position).
10	Make sure that the video cameras are positioned correctly to record the test.
11	Record the filename on the data sheet and make sure that there is adequate media to video record the test.
12	Activate DAS and video recorder.
13	Turn on the pump and check the DAS system for proper operation.
14	Fill the conduit with water and purge as much air as possible from the conduit (approximately 60 psi in hose).

15	Close the inlet and exit water lines.
16	With approximately 0 psig in the hose, measure the overall length of the conduit (LOA1) with the measuring wheel (document on data sheet).
17	Raise the pressure in the conduit to 10 psig.
18	With approximately 10 psig in the hose, measure the overall length of the conduit (LOA2) with the measuring wheel (document on data sheet).
19	Record the rotational position of the vertical marks made in step 9.
20	Raise the pressure in the conduit to working pressure at a continuous rate. The target rate of increase is 200 psig per minute.
21	Wait 5 minutes or until the conduit stops elongating, twisting, and/or snaking. Re-pressurize the conduit as necessary to maintain working pressure.
22	With the conduit at working pressure, measure the overall length of the conduit (LOA3) with the measuring wheel (document on data sheet).
23	Record the rotational position of the vertical marks made in step 9.
24	Turn off the pump.
25	Reduce the pressure in the conduit from working to 10 psig.
26	With approximately 10 psig in the hose, measure the overall length of the conduit (LOA4) with the measuring wheel (document on data sheet).
27	Record the rotational position of the vertical marks made in step 9.
28	Reduce the pressure in the conduit from 10 to approximately 0 psig.
29	With approximately 0 psig in the hose, measure the overall length of the conduit (LOA5) with the measuring wheel (document on data sheet).
30	Record the final rotational position of the vertical marks made in step 9.
31	De-activate the DAS and video recorder.
32	Ensure the video file/tape is labeled.
33	Visually examine the conduit and take photographic records. Also, note the condition of the conduit on the data sheet.
34	Record the test date, working pressure, elongation, and twist on the conduit section with a paint pen.

5.2 Elongation and Twist Test Results

Hose Sample A was subjected to the twist and elongation test. Before the test, a small section of the conduit was cut off to provide hose material for fuel compatibility tests, so the actual length of the hose was less than 100’ at 0 psig. During the test, a baseline conduit length was measured to be 94’9” while at 53 psig. When the conduit was pressurized to the working pressure (650 psig), the conduit elongated to 95’8”, elongating 11 inches from the baseline length. The conduit experienced very little twist after being pressurized. One end of the conduit rotated 45 degrees, and the other end rotated 3 degrees in the same direction. The result is that the conduit experienced a net of 42 degrees rotation.

While setting up the twist and elongation test, it was noted that the conduit had a small pinhole leak. This leak was not caused by the test or from the internal water pressure. It is theorized that the leak was caused in the shipping process. The 100-foot conduit was located at the bottom of the shipping crate and the conduit may have been sitting on a staple holding the cardboard crate together or from a wood splinter on the wood pallet. The leak was noted at low pressure (~60 psig). The pinhole did not appear to grow and the flow rate of the leaking water did not appear to grow either as the water pressure was increased from 60 psig to the working pressure (650 psig).

Figure 5.1, shows the setup of the hose sample for the twist and elongation test and Figure 5.2, shows the pinhole leak that was discovered on the conduit sample. The pressure time-history graphs of the twist and elongation test data can be found in Appendix A.

Figure 5.1 – Hose Sample A – Elongation and Twist Test Setup

Figure 5.2 – Hose Sample A – Pinhole Leak

6.0 FUEL COMPATIBILITY TESTS

6.1 Test Specimens

A short length of the 100 ft hose was used for material for extraction of 15 tensile coupons (Figure 6.1). An ASTM D412-A die was used to stamp out the specimen profile and followed up using a hobby knife and cutting shears to completely remove the specimens from the parent hose material. A representative sample is provided in Figure 6.2. The D412-A die provides samples of approximately 0.5 inches in width and this allows the sample to include a representative number of longitudinal (warp) fibers.

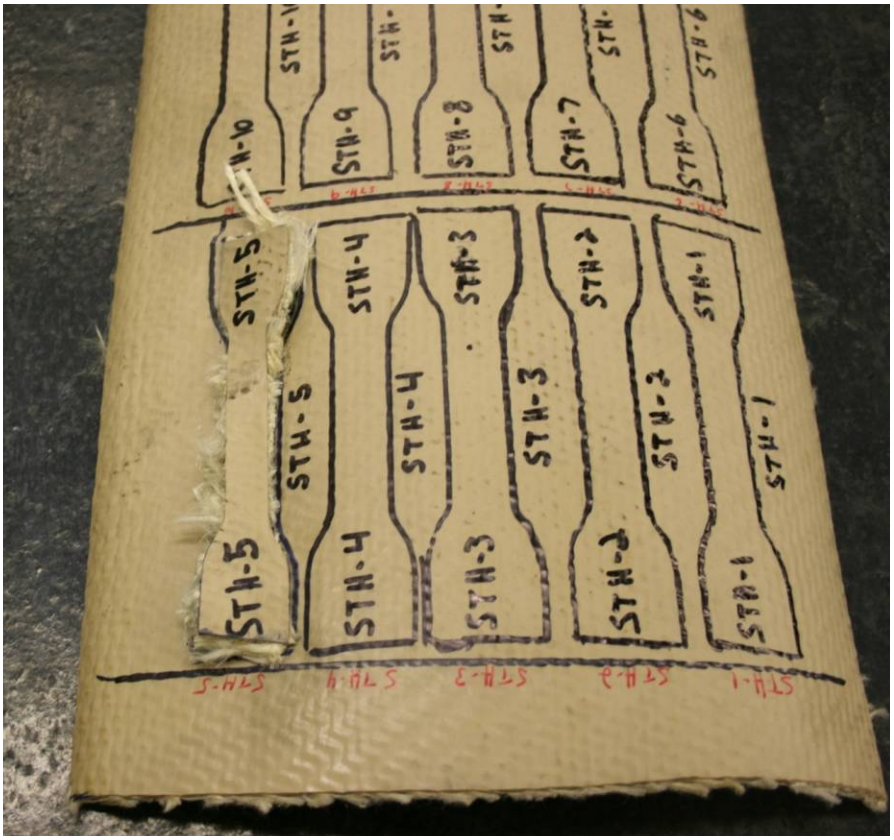


Figure 6.1 - Specimen Layout and Extraction from Parent Hose Section

Figure 6.2 - Representative Tensile Coupon after Removal from Parent Hose Material

Out of the 15 coupons excised for testing, five were maintained and tested to establish the baseline tensile properties. The remaining coupons were provided for soaking in diesel fuel (grade 2), also identified by the label of ULSD Clear AL-21 (four coupons) and the remaining samples were soaked in JP-8 jet fuel and identified as AL-32 JP8 (four coupons). Two coupons were retained for other purposes. At the conclusion of soaking in fuels for 216 hours, the coupons were tested to characterize their after-conditioned tensile properties.

Prior to testing, the nominal specimen cross-sectional dimensions (width and thickness) were measured and used to calculate post-test properties. A unique identification scheme was established to track each specimen through the conditioning and testing process. The results of the testing are presented with respect to each individual test sample.

6.2 Test Procedures

Testing was performed per ASTM D412 at a displacement rate of 20 in/min. A 20-kip servomechanical test frame (Figure 6.3) was used with a 2.5-kip load integrated into the load train given the anticipated loads. Mechanical clamping grips were used to secure each coupon end during testing. A high elongation extensometer was utilized to measure gage length extension during each test. The initial gage length for each test was 2-in and the post-test strain calculations were based on a nominal gage length of 2-in. Testing was performed in laboratory ambient conditions; nominally 72°F and 30-40% RH. It is important to note that the conditioned coupons remained in a bath of their respective conditioning fluid until just prior to testing.

Figure 6.3 – Test Sample Mounted in Tensile Test Frame

Testing was concluded upon specimen failure or the test frame reaching full cross-head travel. Data collected included applied axial load, cross-head displacement, and gage length extension. Post-test processing of the data included determining the continuous axial stress, continuous axial strain, peak stress, and strain at peak stress.

6.3 Test Results

Tabular summaries of the tensile results are shown in Table 6.1. The peak stress and strain at peak stress is included in the table as a means of comparison. In addition, comparative plots are included that graphically compares the results in terms of the peak stress and the strain at peak stress (Figures 6.4 and 6.5, respectively). When comparing mean values, it appears the tensile properties presented show a slight increase with regards to the peak stress achieved while the strain at peak stress decreases for the conditioned coupons as compared to the baseline condition. It important to note that there is significant levels of scatter demonstrated for all conditions tested and a larger sample size would further help understand the change in properties.

In addition to the summary table and plots, representative stress-strain plots are provided for each of the conditions evaluated in Figure 6.6 though 6.8. It is presumed that the rapid increase in stress (stiff behavior) at the beginning of the test is a result of the fibers carrying most of the applied tensile load. However, once those load carrying fibers fail, load is then transferred to the outer, more compliant, coating material and thus the high level of elongation at a lower stress level.

Table 6.1 - Summary of Tensile Results

Condition	Specimen ID	Peak Stress, psi	Average Peak Stress, psi	Standard Dev, psi	Strain at Peak Stress, %	Average Strain at Peak Stress, %	Standard Dev, %
Baseline	STH-11	4980	5169.6	750.6	5.4	4.53	0.66
	STH-12	5569			4.7		
	STH-13	5733			4.5		
	STH-14	5632			4.5		
	STH-15	3934			3.55		
ULSD CLEAR AL-21	STH-6	4579	5489.0	939.2	2.45	4.01	1.41
	STH-7	4787			3.65		
	STH-8	6409			4.1		
	STH-9	6181			5.85		
AL-32 JP8	STH-2	4837	5923.8	1570.6	2.85	3.31	1.32
	STH-3	8009			4.7		
	STH-4	4596			1.7		
	STH-5	6253			4		

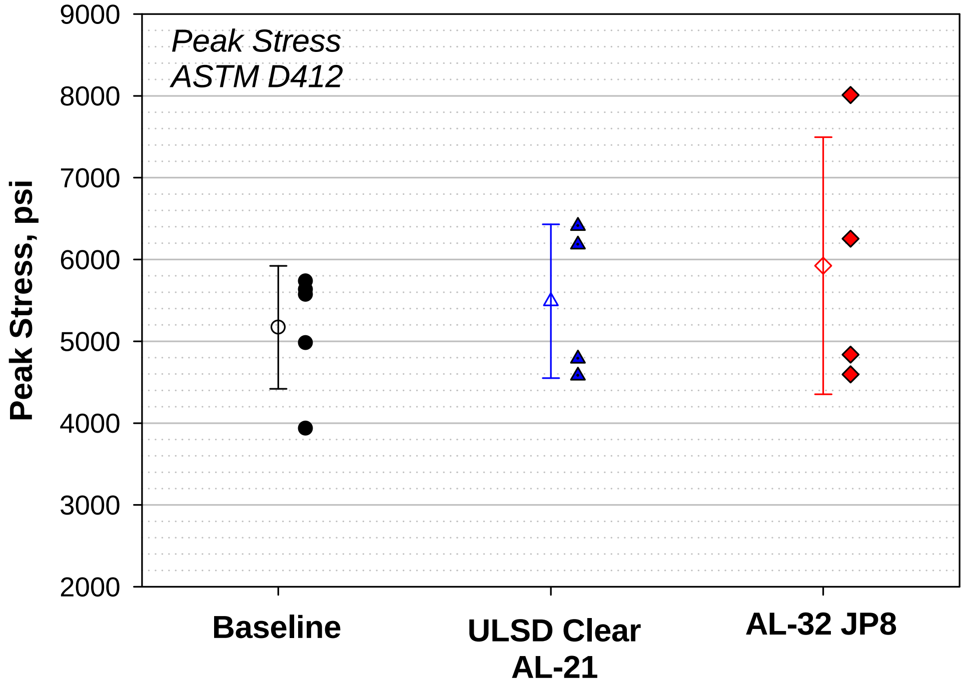


Figure 6.4 - Comparison of the Three Conditions based on the Peak Stress

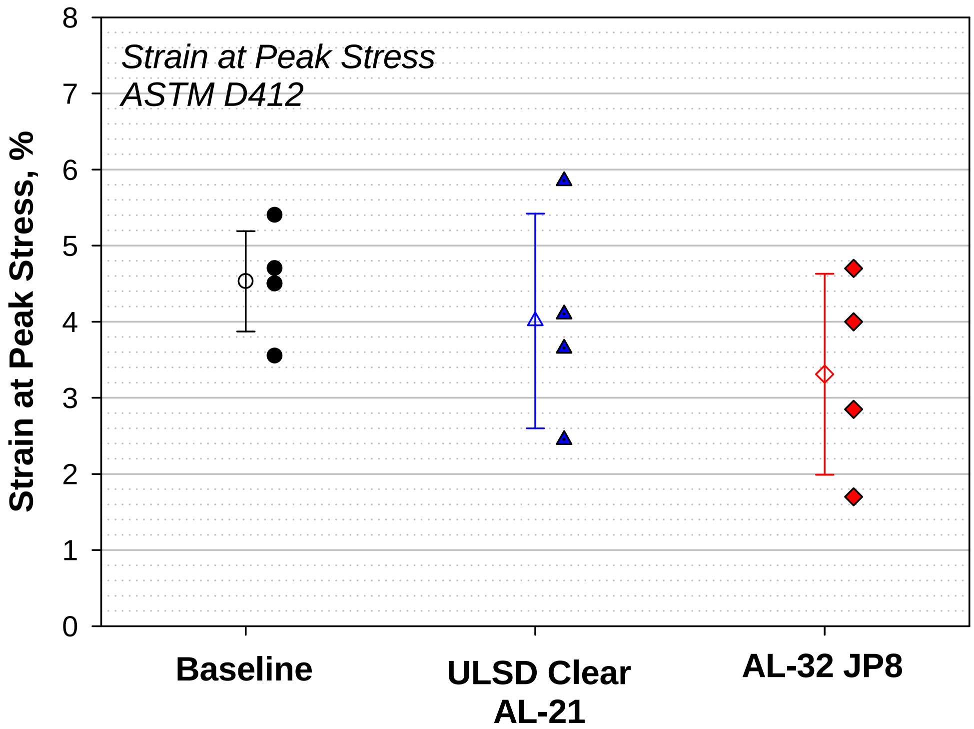


Figure 6.5 - Comparison of the Three Conditions based on the Strain at Peak Stress.

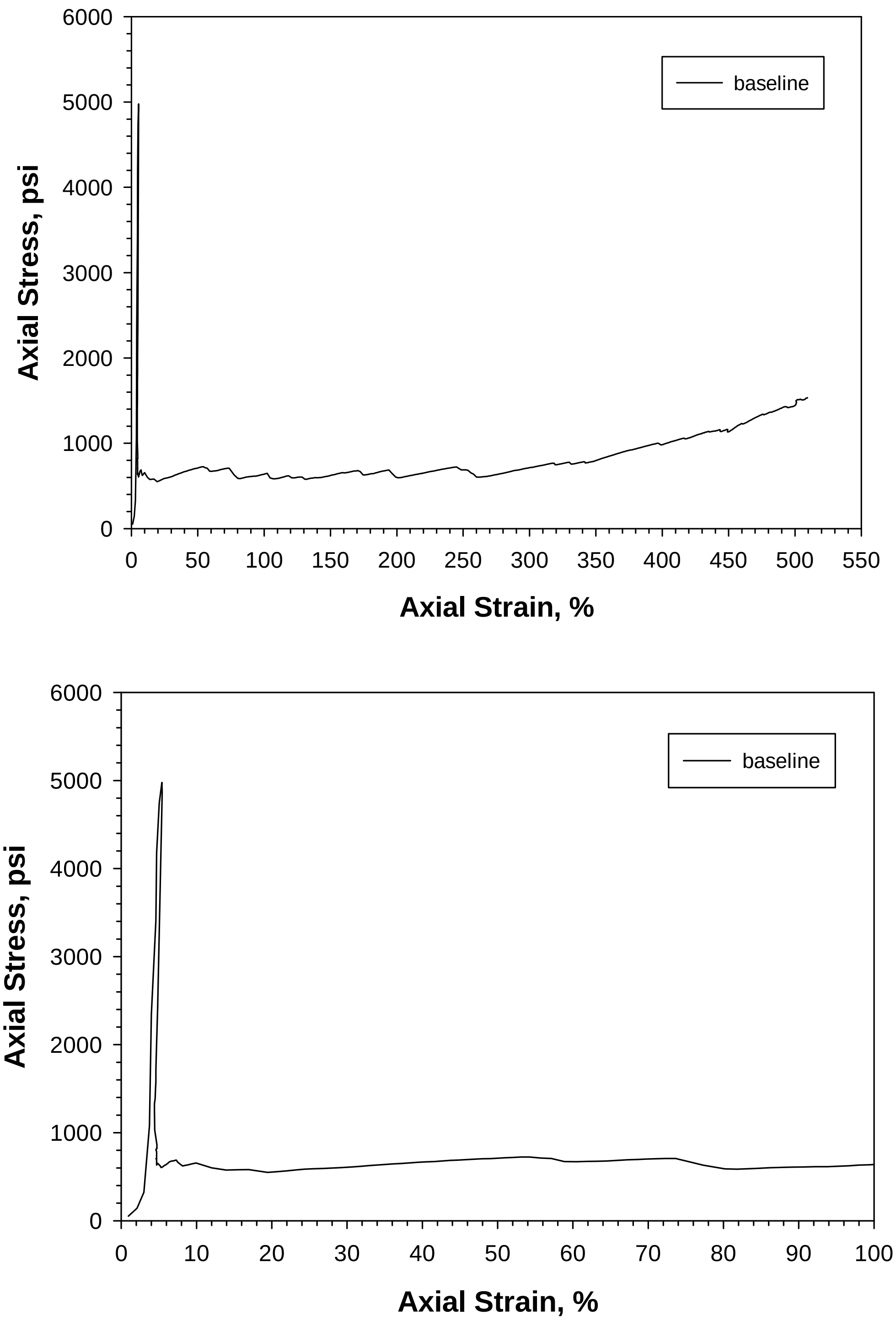
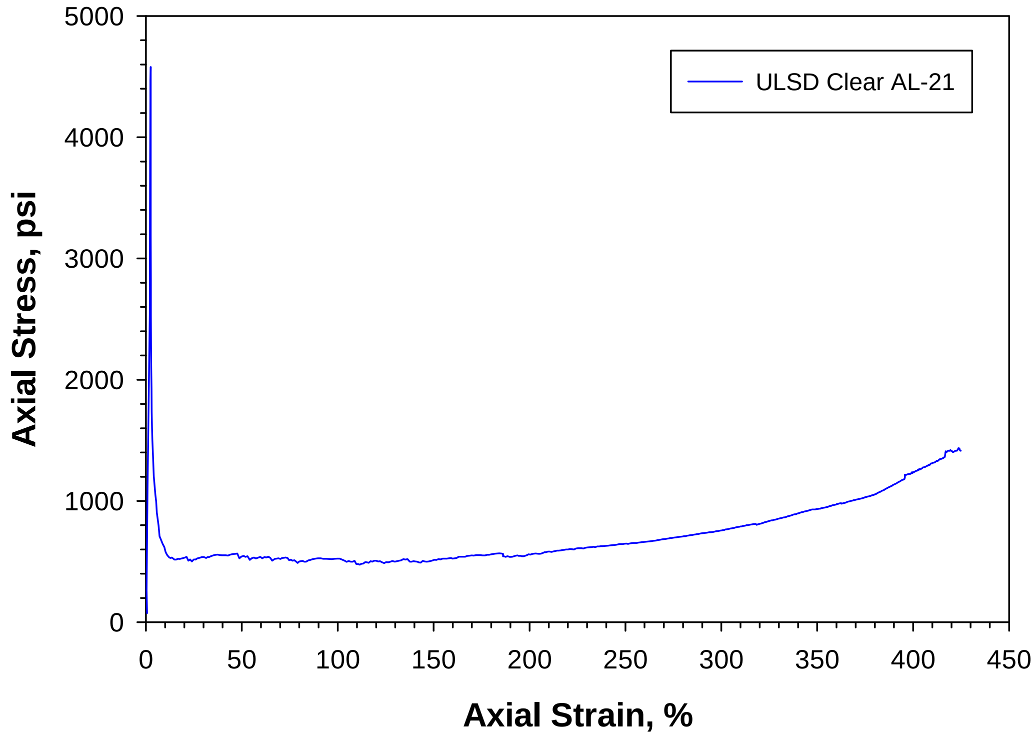


Figure 6.6 - Representative stress-plot behavior for the baseline condition (coupon STH-11).



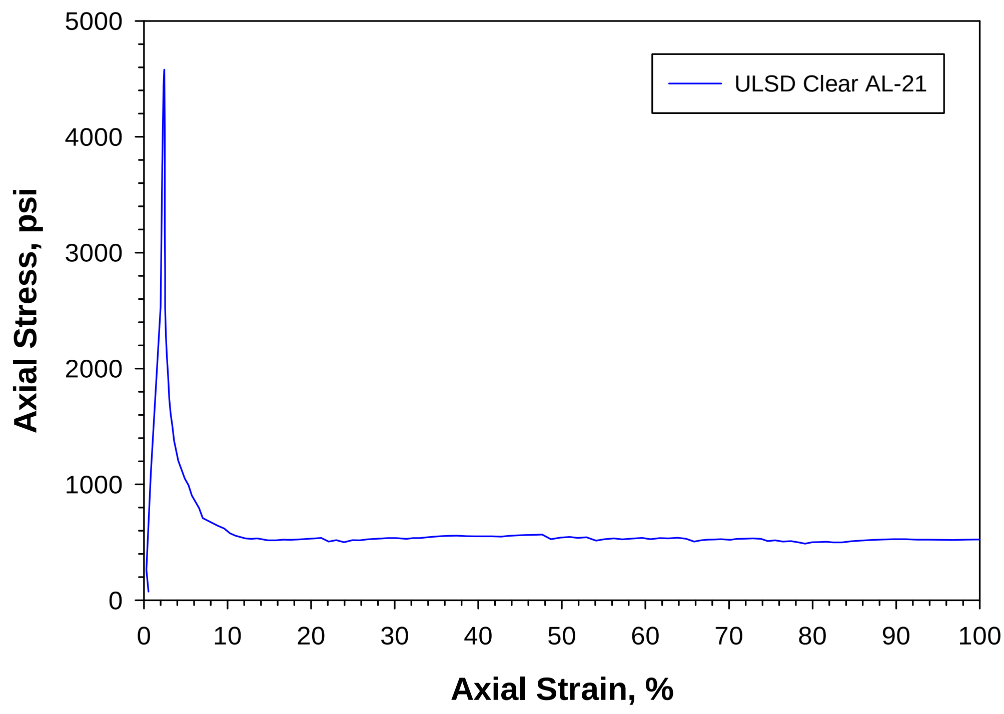
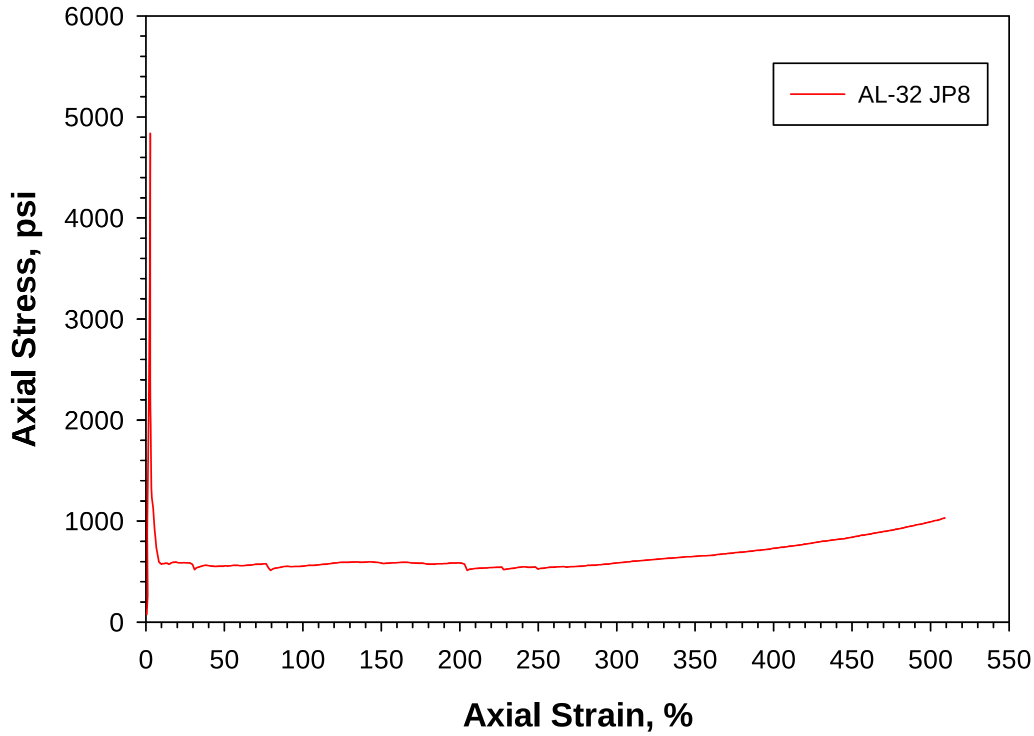


Figure 6.7 - Representative Stress-Plot Behavior for the ULSD Clear AL-21 (coupon STH-6)



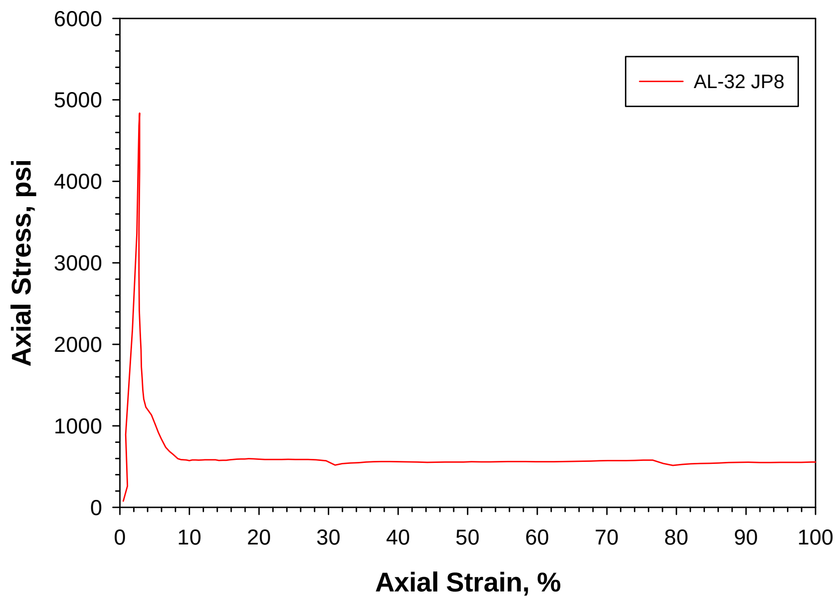


Figure 6.8 - Representative Stress-Plot Behavior for the AL-32 JP8 Condition (coupon STH-2).

7.0 PRESSURE DROP ESTIMATES

Pressure drop per unit distance (mile) at a specified flow rate is an important performance characteristic for hoses because this parameter will set the power requirements and number of pumping stations needed for pumping the fluid. For reference, the pressure drop specification for hose developed for the RIFTS program was "not to exceed 250 ft of fluid per mile at 800 gallons per minute."

The best way to obtain the pressure drop per unit distance is to obtain these measures through flow testing. For best accuracy, several miles of hose, including the prototype couplings, should be laid out on relatively flat terrain and then one would measure the pressure drop at several different flow rates. For enhanced measurement accuracy, the hose diameter variations as a function of internal pressurization should also be recorded so that accurate characterizations of Reynolds number and relative wall roughness can be obtained.

An alternative and less costly method (and less accurate) for characterizing pressure drop would be to calculate the pressure drop based on physical parameters of the hose. With knowledge of the hose surface roughness, one can use a Moody diagram or Colebrook equation to estimate the friction factor. This friction factor is then used in the Darcy-Weisbach equation to calculate pressure drop. In section 7.1, surface roughness measurements are described and in Section 7.2, pressure drop estimates are presented.

7.1 Surface Roughness Measurements

Surface roughness and waviness measurements have been obtained from the inner wall of the hose. See Figure 2.3 for a photograph of the inner wall of the hose carcass. The wall exhibits a wavy wall pattern, which is the dominant wall feature. The pattern is the result of the weave pattern that is impressed through the extruded jacket material that forms the inner wall. Also as shown in Figure 2.3, the pattern results in a spiral feature with a bias angle of 26.5° measured from the axial direction of the hose.

A surface-profiling instrument was used to measure the wavy pattern peak-to-peak height, period, and the surface roughness that is superimposed on the wavy pattern. As shown in Figures 7.1 and 7.2, the surface roughness exhibits a Ra value of 45.4 μinch superimposed on the wavy pattern that exhibits a peak-to-peak height of approximately 0.02 inches. The wave period is about 0.4 inches. If we assumed a sinusoidal shape for the wavy wall (close but not exact), the root-mean-square value (rms) would be 0.707 times the peak height or .00707 inches (0.707 x 0.02/2). For rough order calculations, this would give a hydraulic roughness (e/d) for a nominal 6-inch diameter hose of approximately 0.00707/6 = 0.0012, where the surface roughness is denoted by e and the interior diameter is d. From previous experience, the author has tested a similar hose and has found that the wavy wall roughness controls the pressure drop and not the surface roughness superimposed on the wavy wall.

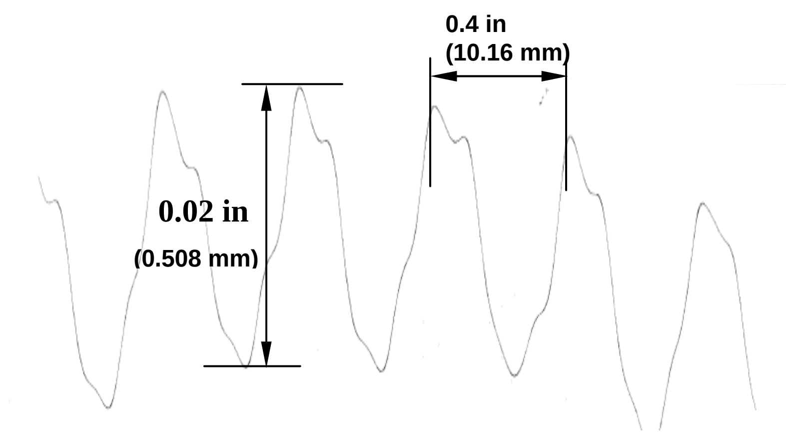


Figure 7.1 - Profile of Wavy Wall (Vertical Scale Amplified)

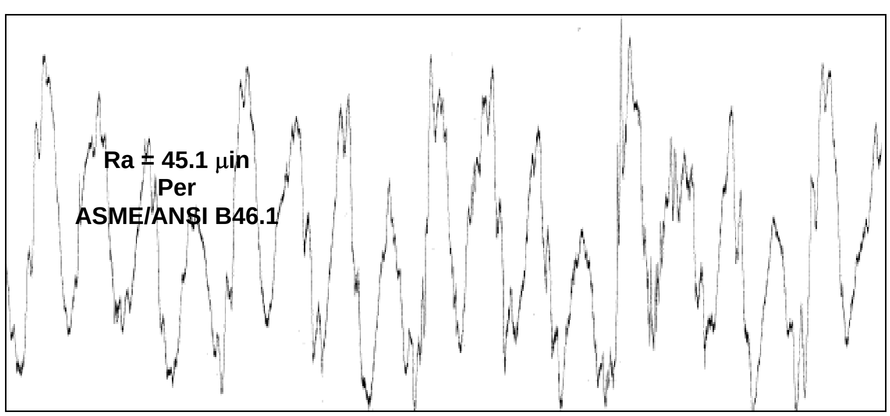


Figure 7.2 - Surface Roughness Profile (Superimposed on Wave Form of Fig. 7.1)

7.2 Pressure Drop Estimate

The Colebrook Equation may be used to calculate friction factor, and for a surface roughness of 0.0012, it is found that the friction factor equals 0.02055 over the range of Reynolds Number from 100,000 to 600,000. See Figure 7.3.

$$1/f^{½} = -2.0 \log ((\varepsilon/D/3.7) + (2.51/Re\, f^{½})) \qquad \text{Eq. 7.1}$$

Where f = friction factor

e= absolute roughness (rms value of roughness)

D= hose diameter

Re = Reynolds Number (= $\mu vD/\rho$)

ρ = fluid density

μ = absolute viscosity

v = velocity of liquid through the hose

Typical Reynolds Numbers are in the highly turbulent flow range and for reference; a 6" diameter pipe that is flowing a kerosene fuel at 800 gallons per minute, the Reynolds Number is approximately 120,000 at 60° F. For a friction of approximately 0.021, the pressure is approximately 285 feet of fluid per mile as calculated by the Darcy-Weisbach equation. See equation 7.2. At 600 gallons per minute, the pressure drop is approximately 165 feet of liquid per mile.

$$h = f(L/D)(v^2/2g) \qquad \text{Eq. 7.2}$$

Where h = head loss in feet of fluid

L = length of hose

g = acceleration due to gravity

The estimated pressure drop per mile at varying flow rates for the Snap-tite developmental hose is presented in Figure 7.4.

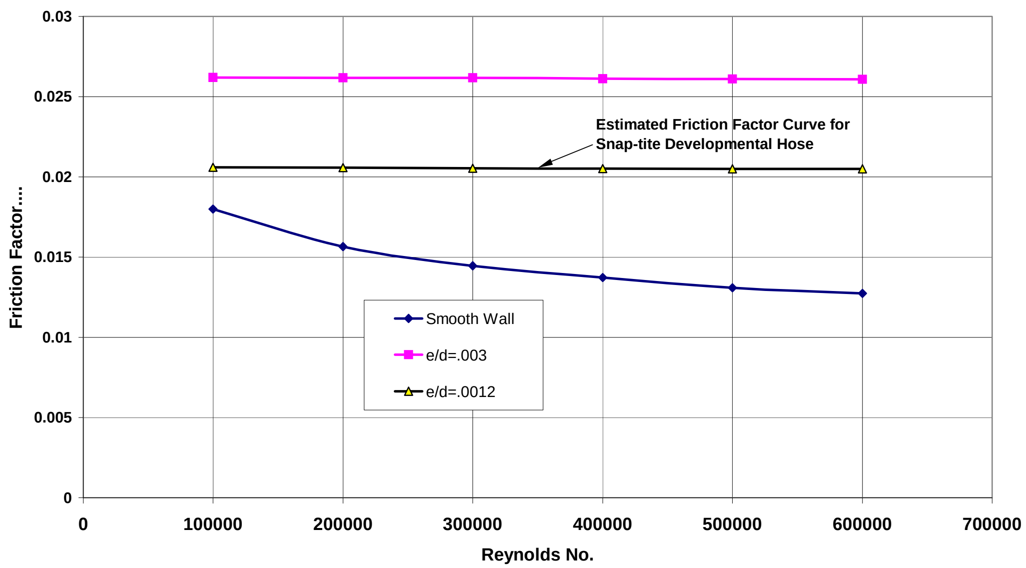


Figure 7.3 - Estimated Friction Factor for Snap-tite Developmental Hose (6 inch Diameter)

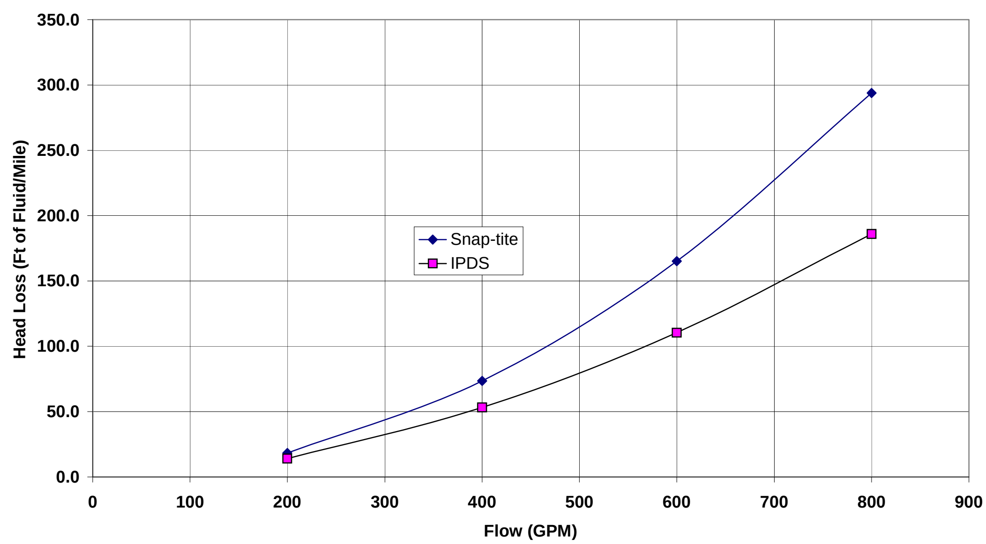


Figure 7.4 - Estimated Pressure Drop of Snap-tite Hose Compared to IPDS 6-inch Piping

For comparison, the pressure drop per mile of smooth wall IPDS piping is also show in Figure 7.4 where it can be seen that the Snap-tite hose exhibits about 50% higher drop as compared to the IPDS piping. The Snap-tite pressure drop could be higher because losses in the couplings have been neglected (although they are expected to be small) and it may be possible for the hose to induce swirl into the fluid by the apparent swirling pattern created by the weave that is impressed through the interior wall. From the author's experience, this pressure drop is in line with similar rough wall hoses. It is cautioned that these estimates are numerically based and it is highly recommended to conduct flow testing for more precise pressure drop predictions.

8.0 CONCLUSIONS AND RECOMMENDATIONS

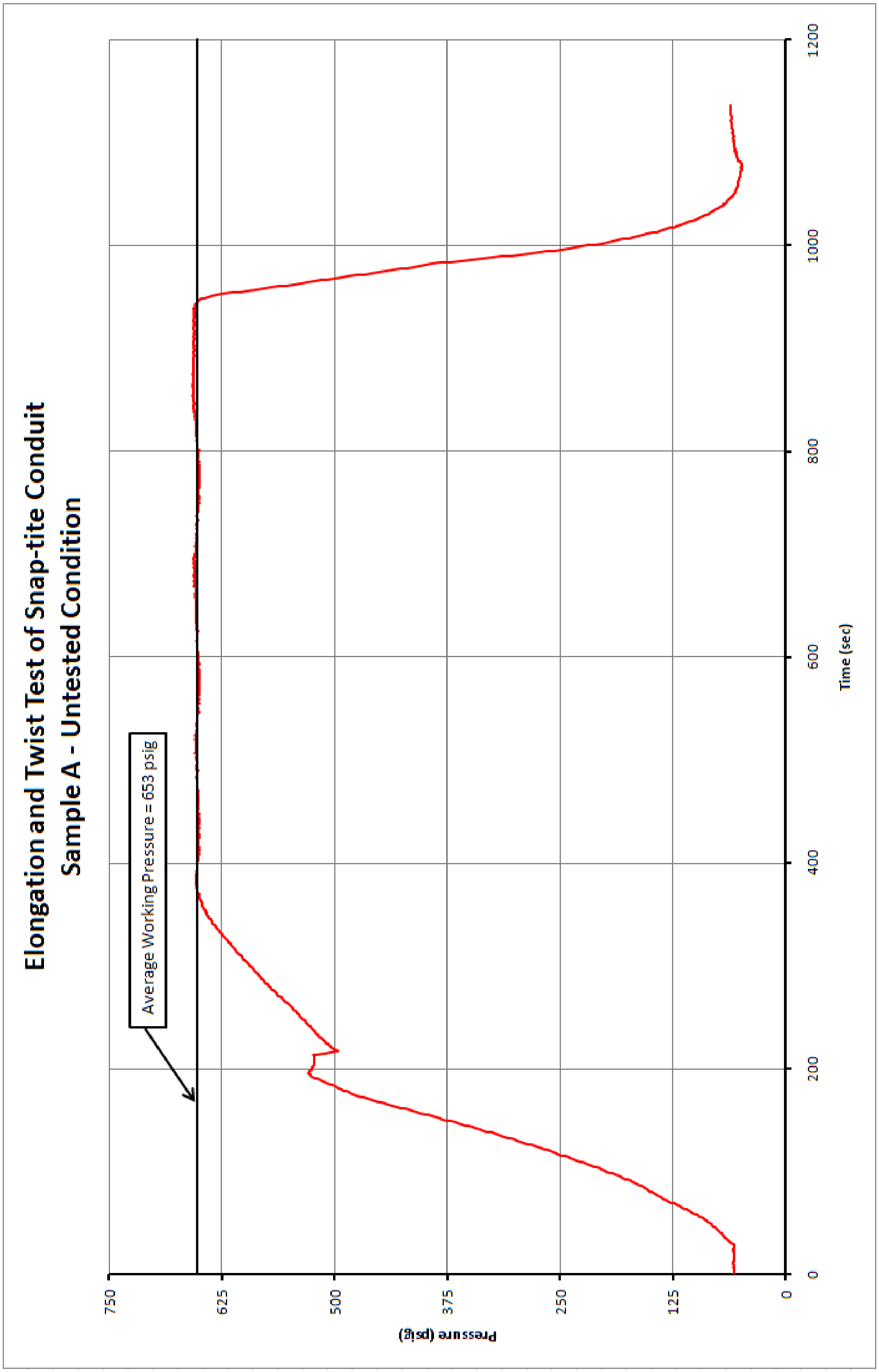
The following conclusions can be drawn from the evaluation of the Snap-tite hose that is described in this study:

- Based on two burst pressures from two samples of new hose, the working pressure with a 3-to-1 safety factor is computed to be 644 pounds per square inch (or a nominal 650 pounds per square inch).
- When new hose is subject to cyclic testing of repeated pressurizations (20 cycles) and repeated flexing (100 cycles), the working pressure based on two burst tests with the cycled hose samples is computed to be 515 pounds per square inch with a 3-to-1 safety factor. This deterioration in working pressure may be caused by excessive rubbing of interior fibers when the hose is flexed by rolling over small diameter rollers. Further investigation of this potential deterioration is recommended.
- A 96.75 foot section of hose when pressurized to a working pressure of 650 psi elongated by eleven (11) inches and thus the computed elongated of the hose is 0.97%.
- The twist for a 96.75 foot section of hose when pressurized to 650 psi working pressure was 0.43 degrees per foot (or 43 degrees of rotation in 100 feet).
- Tensile testing with a small sampling of coupons (5 coupons in a new and raw material form, 4 coupons soaked in Diesel fuel (Grade2), and 4 coupons soaked in JP-8) shows only small variations in mean tensile strength, however the scatter in the data is significant. Coupons were soaked for 216 hours in the test fuels. It is suggested that a large number of samples be used in future testing.

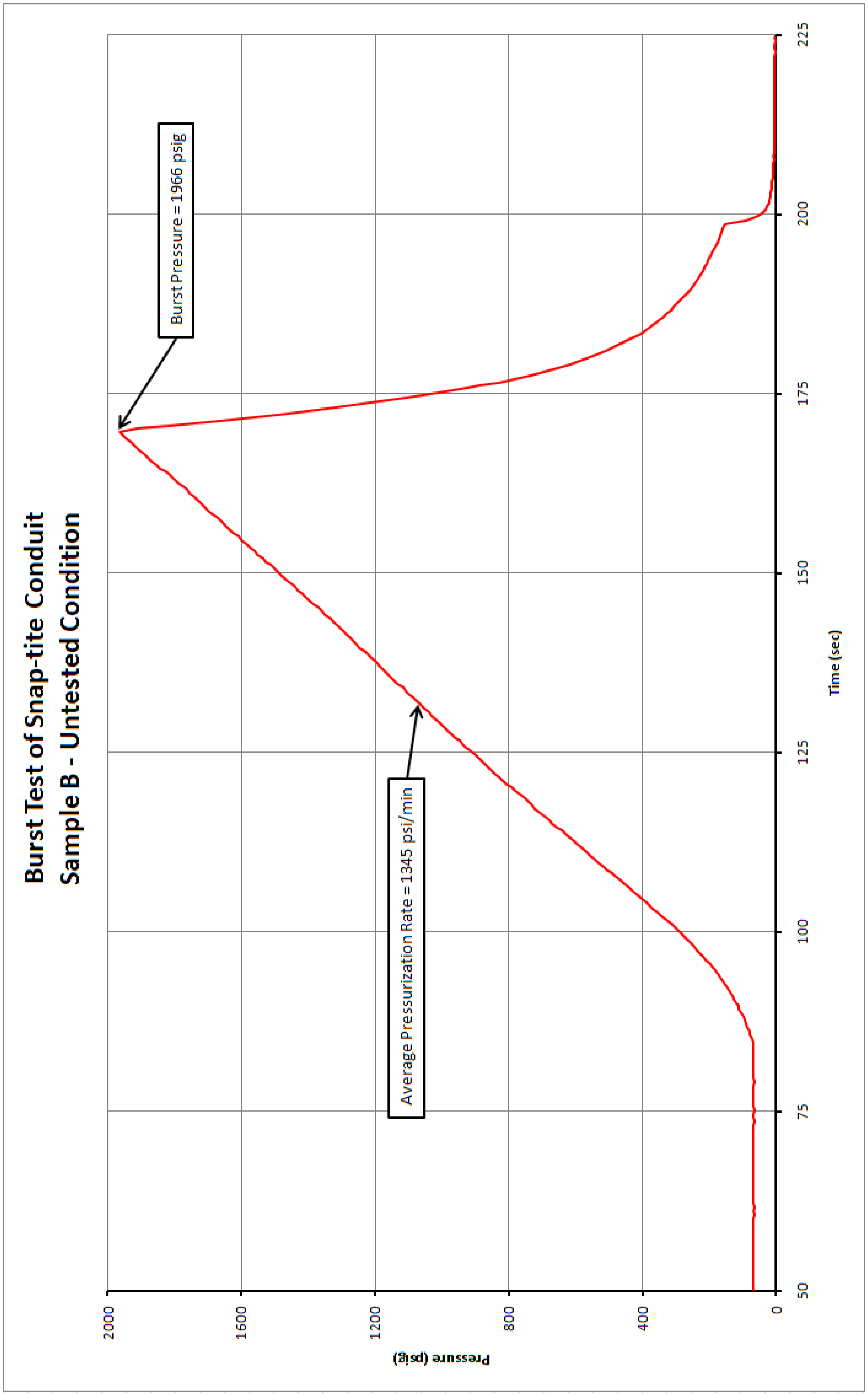
- Pressure drop calculations based on rms roughness values of 0.00707 inch (or an e/d = 0.0012) indicate that the Snap-tite hose will exhibit pressure drops of 285 feet of fluid at 800 GPM and 165 feet of fluid at 600 GPM. This would compare to the smooth wall IPDS piping which exhibits pressure drops of 185 feet of fluid at 800 GPM and 110 feet of fluid at 600 GPM. It is suggested that actual flow testing be accomplished with the Snap-tite hose at working pressure to obtain a measured pressure drop.
- The hose exhibits low weight (1.18 lbs/ft) and it does lay flat.
- The couplings are of unique design and are easily and rapidly installed (less than thirty minutes to install two couplings and connect the ends). The couplings never failed under burst test conditions and they did not leak.
- It is recommended that design improvements be considered for the coupling to (1) reduce length of the coupling, (2) chamfer sharp edges, and (3) minimize flow losses created by interior sharp edges.
- While the thickness of the wall (injected material) is sufficient to maintain pressure integrity, it is not of uniform thickness. This could lead to areas of weakness especially if a “fold line” develops in the areas of smallest thickness. Therefore, it is recommended that the hose be produced with sufficient and uniform thickness.
- Based on the overall results of the screening tests and hydraulic analysis, it appears that the Snap-tite lay flat, 6-inch diameter hose and couplings are good candidates for further development for supplementing or replacing IPDS conduit. The improved hose system should then be subjected to rigorous qualification testing in both hot and cold environments.

APPENDIX A

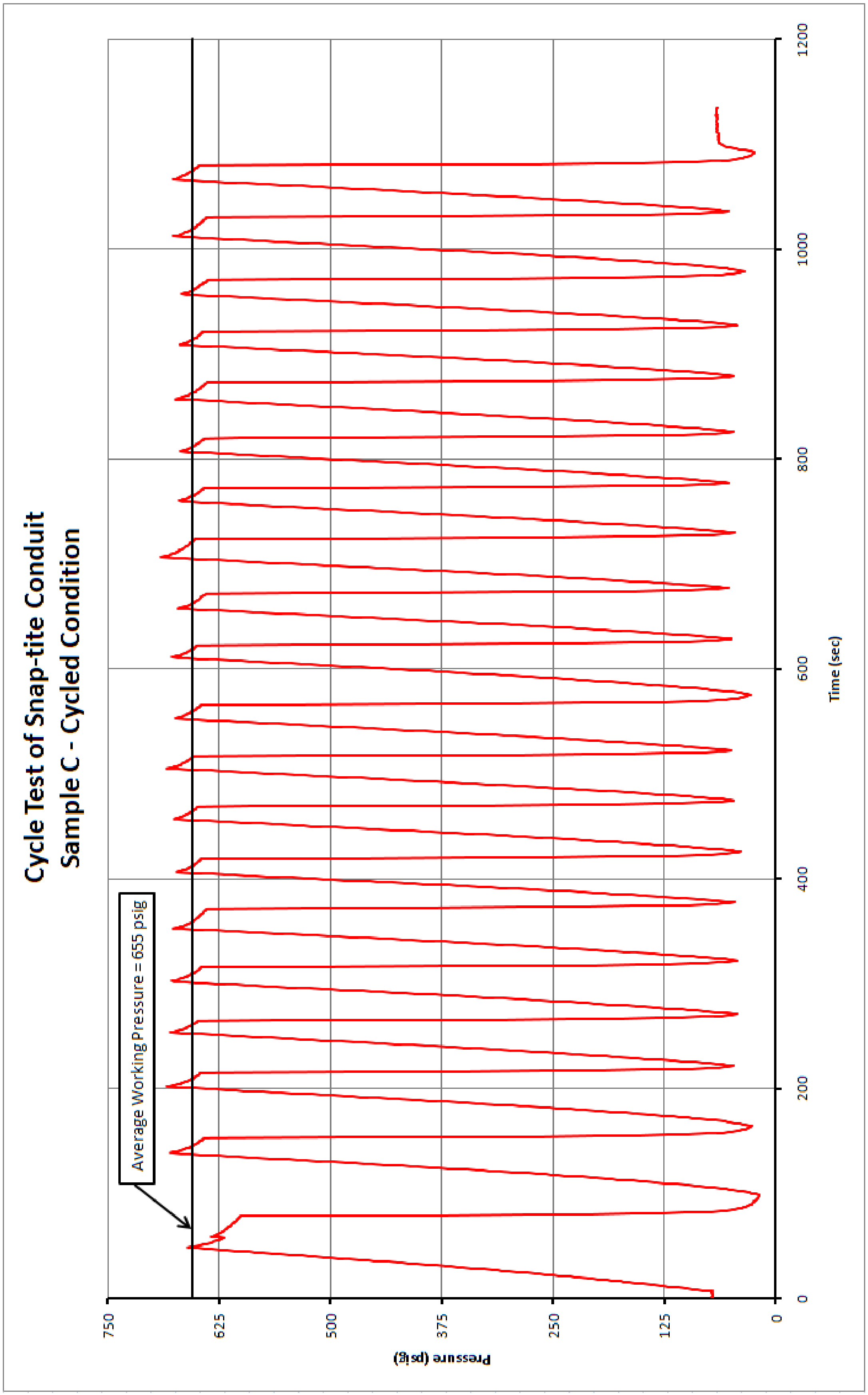
Graphs of Hydrostatic Test Data



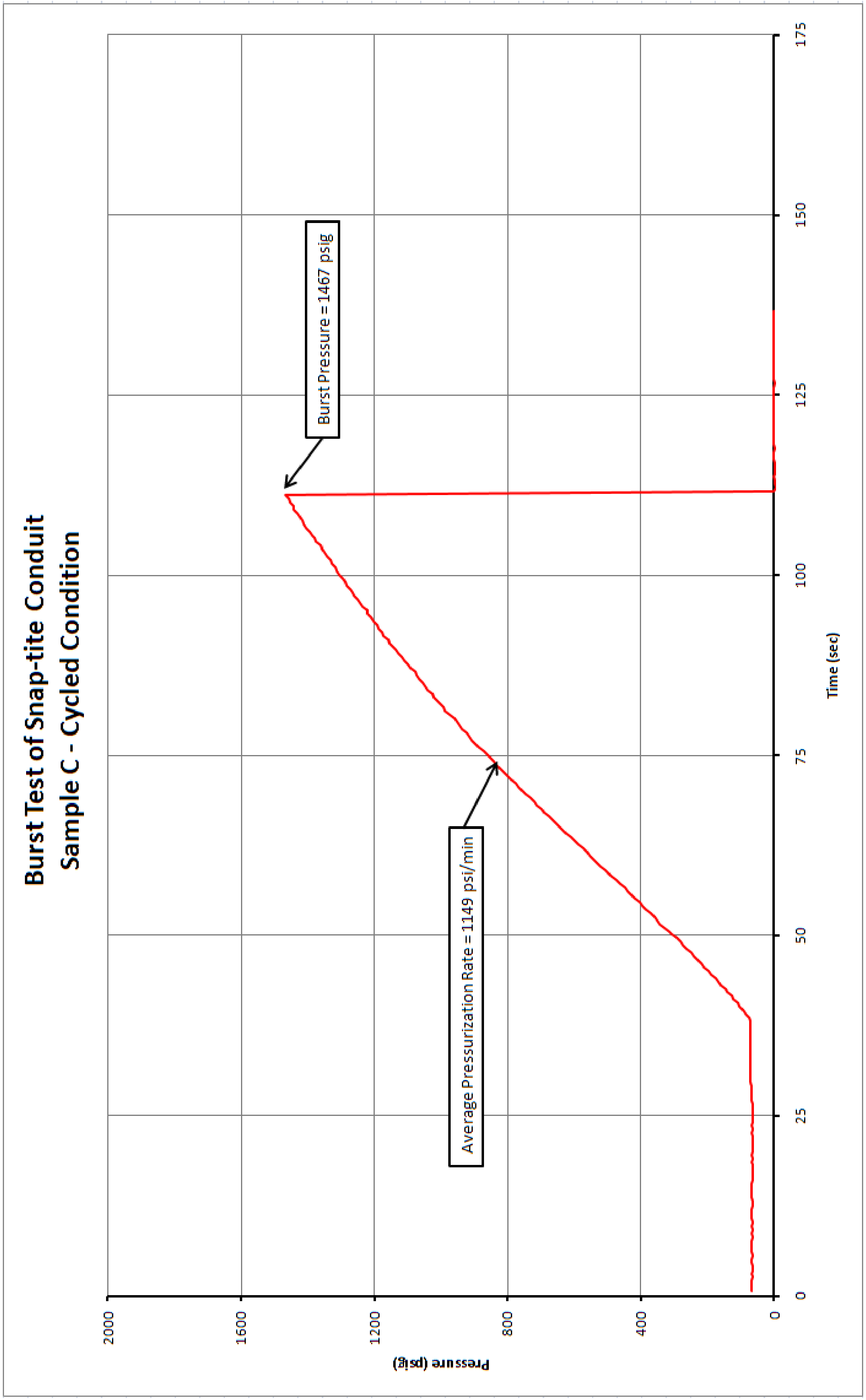
Elongation and Twist Test of Snap-tite Conduit
Sample A - Untested Condition
Average Working Pressure = 653 psig
Pressure (psig)
750
625
500
375
250
125
0
Time (sec)
0
200
400
600
800
1000
1200



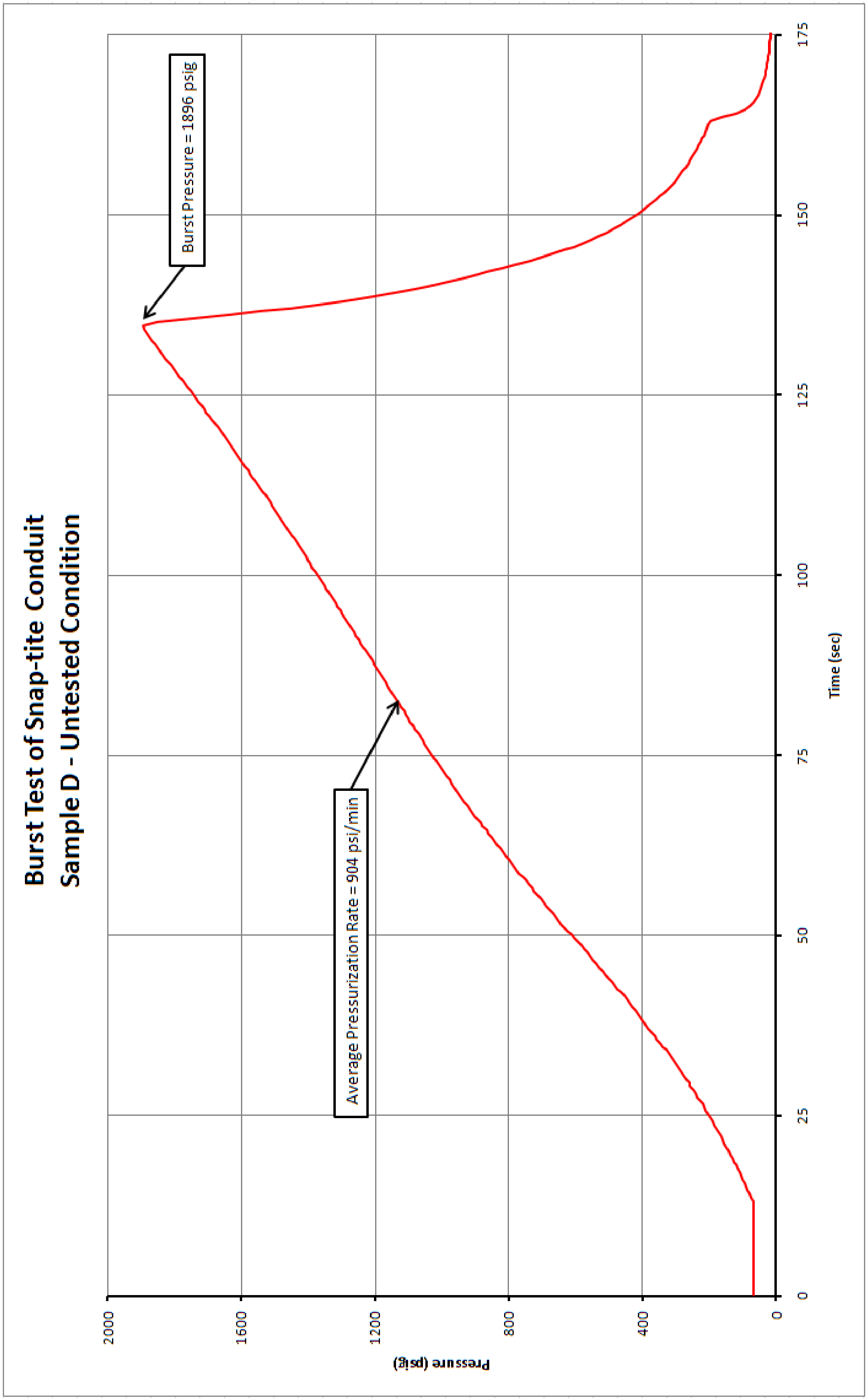
Burst Test of Snap-tite Conduit
Sample B - Untested Condition
Burst Pressure = 1966 psig
Average Pressurization Rate = 1345 psi/min
Pressure (psig)
2000
1600
1200
800
400
0
Time (sec)
50
75
100
125
150
175
200
225

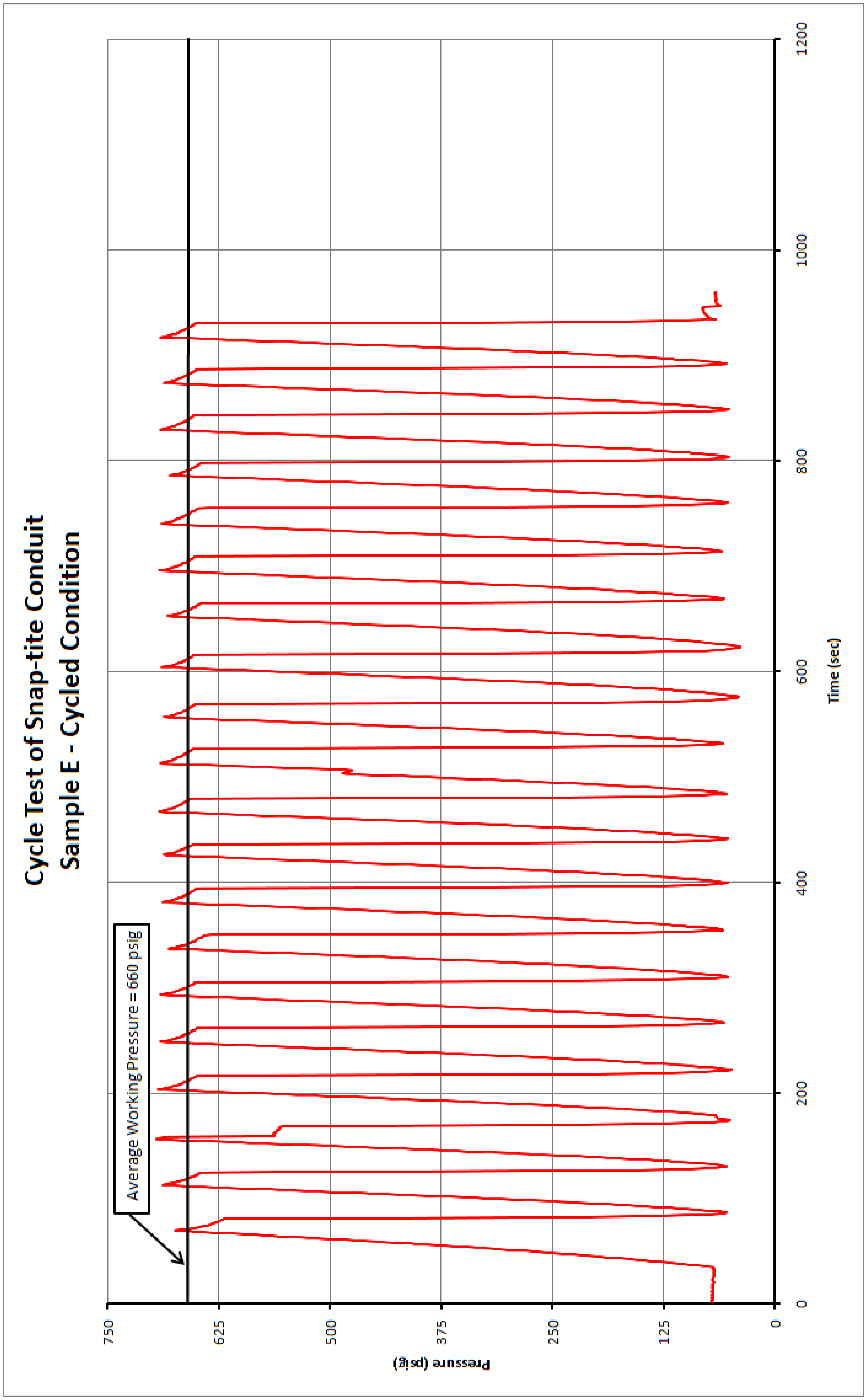


Cycle Test of Snap-tite Conduit
Sample C - Cycled Condition
Average Working Pressure = 655 psig
Pressure (psig)
Time (sec)
0
125
250
375
500
625
750
0
200
400
600
800
1000
1200

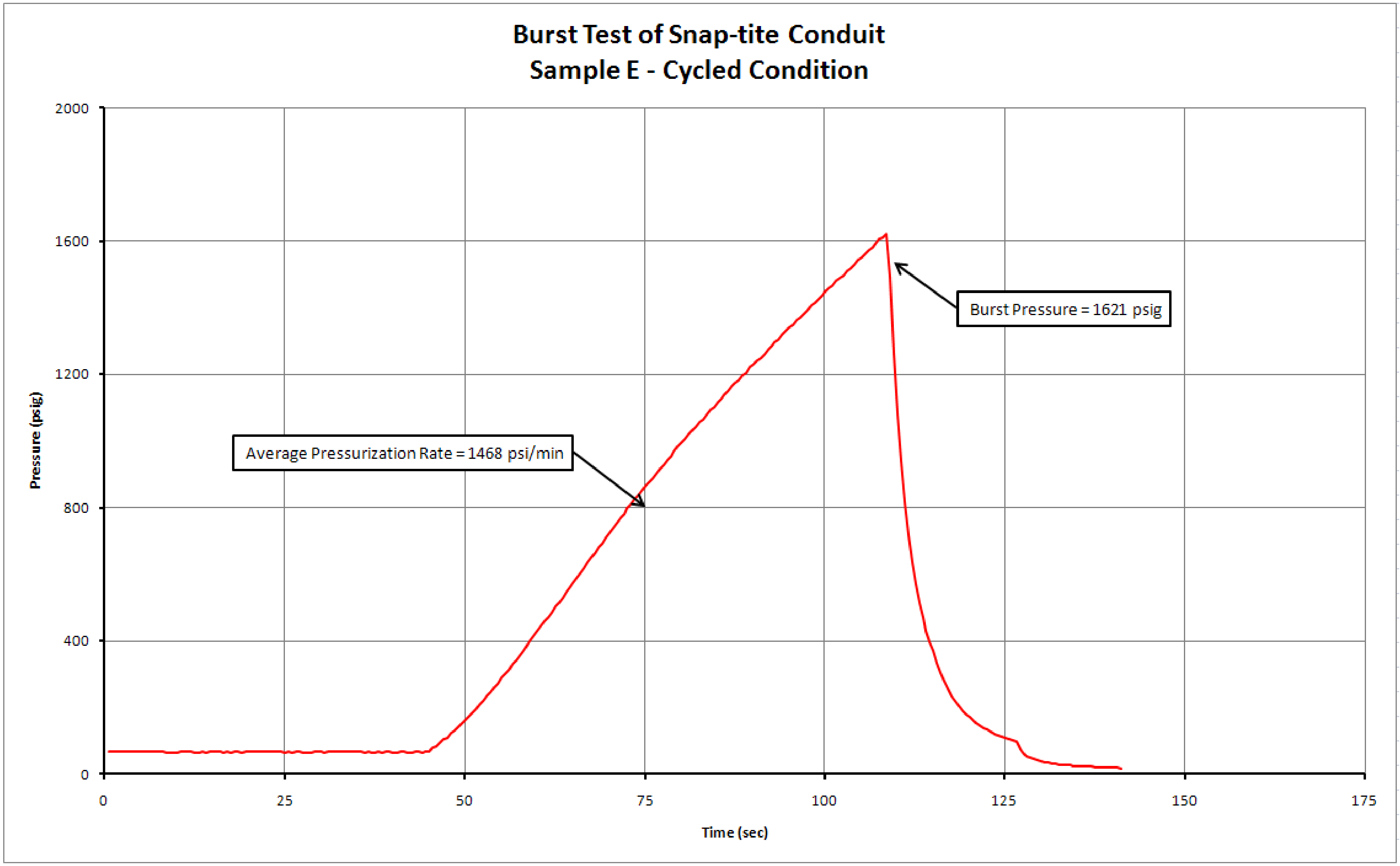


Burst Test of Snap-tite Conduit
Sample C - Cycled Condition
Burst Pressure = 1467 psig
Average Pressurization Rate = 1149 psi/min
Pressure (psig)
Time (sec)
0
400
800
1200
1600
2000
0
25
50
75
100
125
150
175


Burst Test of Snap-tite Conduit
Sample D - Untested Condition
Burst Pressure = 1896 psig
Average Pressurization Rate = 904 psi/min
Pressure (psig)
2000
1600
1200
800
400
0
Time (sec)
0
25
50
75
100
125
150
175



Cycle Test of Snap-tite Conduit
Sample E - Cycled Condition
Average Working Pressure = 660 psig
Pressure (psig)
750
625
500
375
250
125
0
Time (sec)
0
200
400
600
800
1000
1200


Burst Test of Snap-tite Conduit
Sample E - Cycled Condition
Pressure (psig)
2000
1600
1200
800
400
0
0
25
50
75
100
125
150
175
Time (sec)
Average Pressurization Rate = 1468 psi/min
Burst Pressure = 1621 psig

APPENDIX B

Hydrostatic Test Data Sheets

Snap-Tite Conduit Hydrostatic Burst Test Datasheet

Conduit Test Sample Number: A	Date: 9/15/2009 ~ 2:15 PM up to working
Date of Manufacture: N/A	

Prerequisite

Visual Inspection Notes: see notebook
42" cut from one end for Jim Johnson to use for testing
650 psig working pressure

Calibration Information

Pressure transducer: OMEGA PX329-5KG5V	Temperature at test time
Mod# S/N: 060908D330	End 1: EAST 82°F
Cal date: 9/11/2009	Ambient: 89°F
Cal due date: N/A	End 2: N/A

Hydrostatic Test

LOA2: end fitting angled
Down hill UPHILL

			CIRC. DIA. MEAS VIA π TAPE
INITIAL	Conduit Length (LOA1): 94' 9 3/4" (in) @ 0 psig		
≈53 psi	Conduit Length (LOA2): 94' 9" (in)	Conduit Twist: 4° cw 2° cw (degrees)	6.505 Ø
W.P. 92'-8 1/2"	Conduit Length (LOA3): 95' - 10 3/4 8" (in)	Conduit Twist: 3° cw 45° ccw (degrees)	6.635
CITY 60psi	Conduit Length (LOA4): 92'-1 3/8" 95' - 1 1/4" (in)	Conduit Twist: 2° ccw 43° ccw (degrees)	6.580
0 psi	Conduit Length (LOA5): 92'-1/2" 95 - 1 5/8" (in)	Conduit Twist: 0° 30° ccw (degrees)	6.400

Data filename: Elong A

Video record (circle): Yes No

Video tape ID # N/A

NEW MARKS

Test notes/observations:

pin hole leak documented in photos
also leaks at end fittings

Testing Personnel:

[signature] 9-15-09
Test Technician(1) Date

[signature] 9/15/2009
Test Engineer Date

[signature] 9-15-09
Test Technician(2) Date

4

Snap-Tite Conduit Hydrostatic Burst Test Datasheet

Conduit Test Sample Number: B	Date: 9/14/2009 ~ 11 AM
Date of Manufacture: N/A	

Prerequisite:

Visual Inspection Notes: see notebook

Calibration Information:

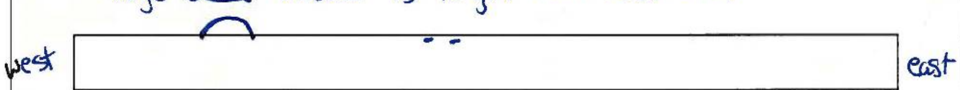
Pressure transducer: OMEGA PX309-5KG5V	Temperature at test time
Mod# S/N: 060908D330	End 1: EAST ~~[illegible]~~ 76 °F
Cal date: 9/11/2009	Ambient: 77°F
Cal due date: N/A	End 2: WEST ~~[illegible]~~ 77 °F

Hydrostatic Test city: 157 in. | inside 140 in. ← @~60 PSI

Conduit Length (LOA): 157 (in)	Length between shank ends: 140 (in) ← @10PSI
Peak Pressure (psig): 1966	Failure Mode: (holes) crack in liner
Data filename: Burst B	Video record (circle) Yes / No
Video tape ID # Burst B	

Test notes/observations:

small splits about half way down length of hose
large ~~[illegible]~~ bubble 1/3 length from west end



Conduit Section – Indicate Burst Location and Bending Locations

Testing Personnel:

[signature]	9-14-09	Oliver Harrison	9/14/2009
Test Technician(1)	Date	Test Engineer	Date
Donald E. [signature]	9-14-09		
Test Technician(2)	Date		

3

Snap-Tite Bending and Pressure Cycle Tests

Conduit Test Sample Number: C	Date: 14 SEP 2009
Date of Manufacture: N/A	

Prerequisite counterweight = 142 lbs.

Visual Inspection Notes: SEE RECEIVING INSPECTION. NO ADD'L INDICATIONS DUE TO INSTALLATION IN TEST FRAME

Calibration Information

Pressure transducer: OMEGA PX329-5KG5V	Temperature at test time
Mod# S/N: 060908D330	End 1: EAST 79°F End 2: WEST 80°F
Cal date: 9/11/2009 Cal due date: N/A	Ambient: 80°F

Bend Cycle Test

Conduit Length (LOA): 211 1/2 (in) OE-to-OE	Length between shank inside ends: 195 3/4 (in)
Data filename: N/A	Start Time: 13:39
Time at 50 Cycles: 2:01pm 14:01	Time at 100 Cycles: 2:27pm 14:27

at time of pressure cycles

Pressure Cycle Test

Conduit Length (LOA): 213 (in)	Length between shank inside ends: 195 3/4 (in)
LOA after 20 Cycles: 213 5/8 (in) @60 psi	Length between shank ends: 196 5/8 (in)
Data filename: Cycle C	Video record (circle): Yes / No
Video tape ID #: N/A	working pressure: 650 psig

Test notes/observations" Extreme" marks are 8" from one end and 65 3/4" from the other end.

Some elongation after cycles (pressure)

8" 65 3/4"

≅32 → Axially oriented tear, approx. " long

Burst info, see next sheet

Conduit Section – Indicate Bend Locations

Testing Personnel:

[signature]	9-14-09	Oliver Hansen	9/14/2009
Test Technician(1)	Date	Test Engineer	Date
Donald C. Mossy	9-14-09		
Test Technician(2)	Date		

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Snap-Tite Conduit Hydrostatic Burst Test Datasheet

Conduit Test Sample Number: C	Date: 9/14/2009 ~4 PM
Date of Manufacture: N/A	

Prerequisite

Visual Inspection Notes: see notebook

note that during some of the bending cycles, the hose was riding on the edge of the main drum; this may or may not have effected the burst pressure

Calibration Information

Pressure transducer: PX 309 5KG5V OMEGA	Temperature at test time
Mod# S/N: 0609081330	End 1: EAST 80°F
Cal date: 9/11/2009	Ambient: 81°F
Cal due date: N/A	End 2: WEST 80°F

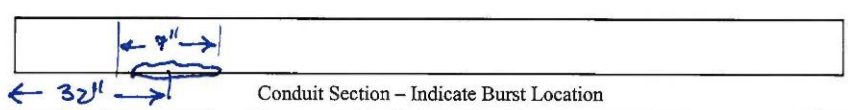
Hydrostatic Burst Test @ 60 psi

Conduit Length (LOA): 213 5/8 (in)	Length between shank ends: 196 5/8 (in)
Peak Pressure (psig): 1466	Failure Mode: axially oriented tear, approx 7" long, ~~located approx~~ on the fold
Data filename: Burst C	Video record (circle): Yes / No
Video tape ID # Burst C	

Test notes/observations

hose ruptured in 1 axially oriented tear, approx 7" long. located along the fold (approx.)

approx. 65-75 circumferential threads failed



Conduit Section – Indicate Burst Location

Testing Personnel:

[signature]	9-14-09	[signature]	9/14/2009
Test Technician(1)	Date	Test Engineer	Date
[signature]	9-14-09		
Test Technician(2)	Date		

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Snap-Tite Conduit Hydrostatic Burst Test Datasheet

Conduit Test Sample Number: D	Date: 9/14/2009 ~ 1:30 PM
Date of Manufacture: N/A	

Prerequisite:

Visual Inspection Notes: see notebook

Calibration Information:

Pressure transducer: OMEGA PX329-5KG-5V	Temperature at test time
Mod# S/N: 0609080330	End 1: EAST 80°F
Cal date: 9/11/2009	Ambient: 78°F
Cal due date: N/A	End 2: WEST 78°F

Hydrostatic Test @ 60 psi

Conduit Length (LOA): 179 (in)	Length between shank inside ends: 162 (in)
Peak Pressure (psig): 1896	Failure Mode: Crack (split)
Data filename: Burst D	Video record (circle): Yes / No
Video tape ID # Burst D	break in circumferential yarn

Test notes/observations:

crack (split) about 1/3 from east end

yarn sticking out

west — east

Conduit Section – Indicate Burst Location and Bending Locations

Testing Personnel:

9-14-09

Test Technician(1) Date

9/14/2009

Test Engineer Date

9-14-09

Test Technician(2) Date

3

Snap-Tite Bending and Pressure Cycle Tests

Conduit Test Sample Number: E	Date: 15 SEP 2009
Date of Manufacture:	

Prerequisite counterweight = 142 lbs.

Visual Inspection Notes: SEE RECEIVING INSPECTION, NO Apparent DAMAGE during installation of test sample.

Calibration Information

Pressure transducer: OMEGA PX329-5KG-5V	Temperature at test time
Mod# S/N: 0609080330	End 1: EAST 78 °F End 2: WEST 80 °F
Cal date: 9/11/2009 Cal due date:	Ambient: ~~75 °F~~ 76 °F

Bend Cycle Test 171" END-to-END (bare hose) from receiving inspection

Conduit Length (LOA): 170 3/4 (in)	Length between shank ends: 153 1/2 (in)
Data filename: N/A	Start Time: ≈ 8:45
Time at 50 Cycles: 09:10	Time at 100 Cycles: 09:33

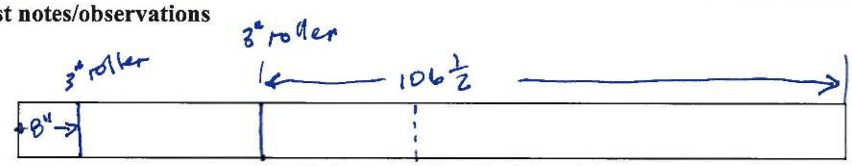
out same time

Pressure Cycle Test @ 60 psig inside

Conduit Length (LOA): 170 3/4 (in)	Length between shank ends: 153 1/2 (in)
LOA after 20 Cycles: 171 3/4 (in)	Length between shank ends: 154 5/8 (in)
Data filename: Cycle E	Video record (circle): Yes No
Video tape ID #: N/A	

holding between 650 and 675 psig

Test notes/observations



Conduit Section – Indicate Bend Locations

Testing Personnel:

Test Technician(1): [signature] Date: 9-15-2009

Test Engineer: [signature] Date: 9/15/2009

Test Technician(2): Donald F. Massey Date:

4

Snap-Tite Conduit Hydrostatic Burst Test Datasheet

Conduit Test Sample Number: E	Date: 15 Sep 2009 ~10:45AM
Date of Manufacture:	

Prerequisite

Visual Inspection Notes: OK – no apparent damage or coupling movement from cyclic test

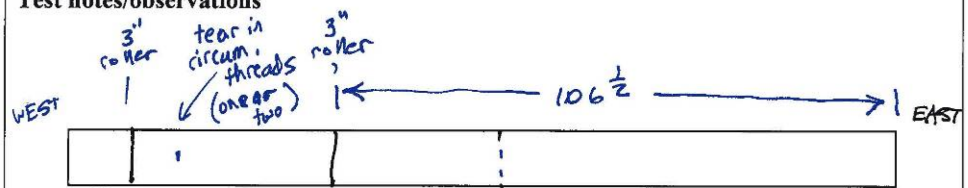
Calibration Information

Pressure transducer: OMEGA #PX329-5KG5V	Temperature at test time
Mod# S/N: 0609080330	End 1: EAST 82°F
Cal date: 9/11/2009	Ambient: 78°F
Cal due date: N/A	End 2: WEST 81°F

Hydrostatic Burst Test

Conduit Length (LOA): 171 3/4 (in)	Length between shank ends: 154 5/8 (in)
Peak Pressure (psig): 1621	Failure Mode: Circumferential thread tear (one or two threads)
Data filename: Burst E	Video record (circle): Yes / No
Video tape ID #: Burst E	

Test notes/observations



Conduit Section – Indicate Burst Location

Testing Personnel:

[signature]	9-15-09	[signature]	9/15/2009
Test Technician(1)	Date	Test Engineer	Date
[signature]	9-15-09		
Test Technician(2)	Date		

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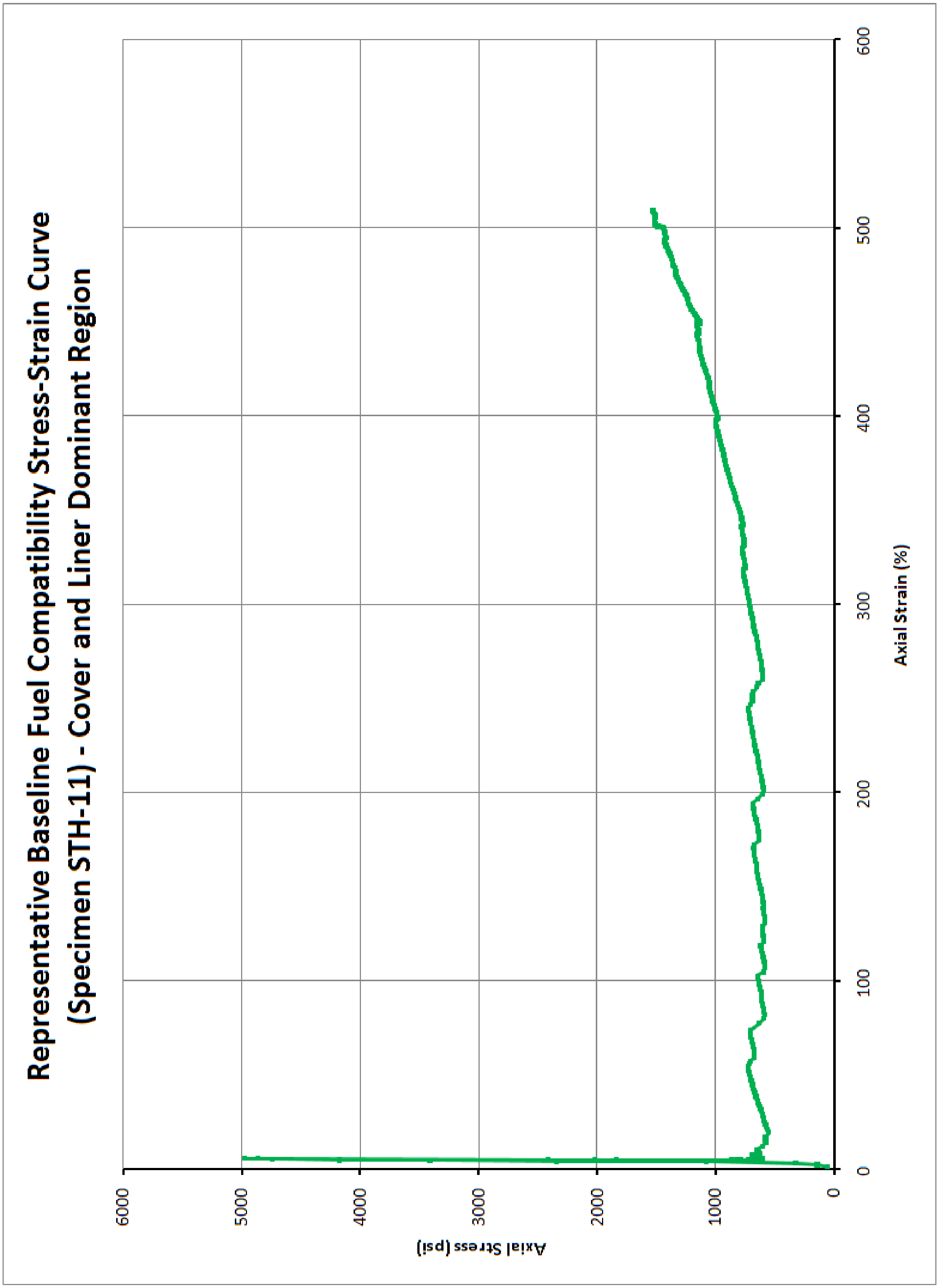
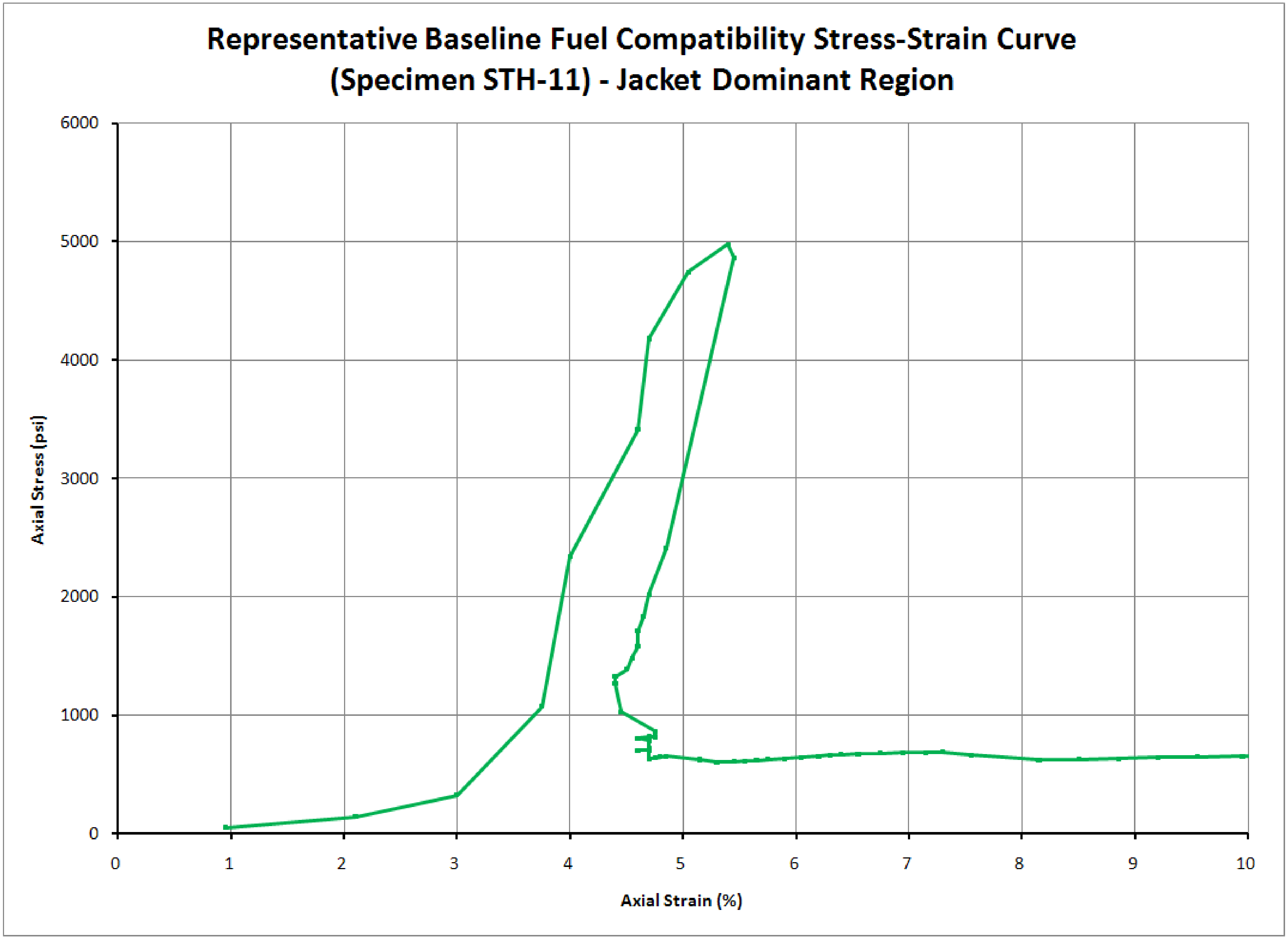
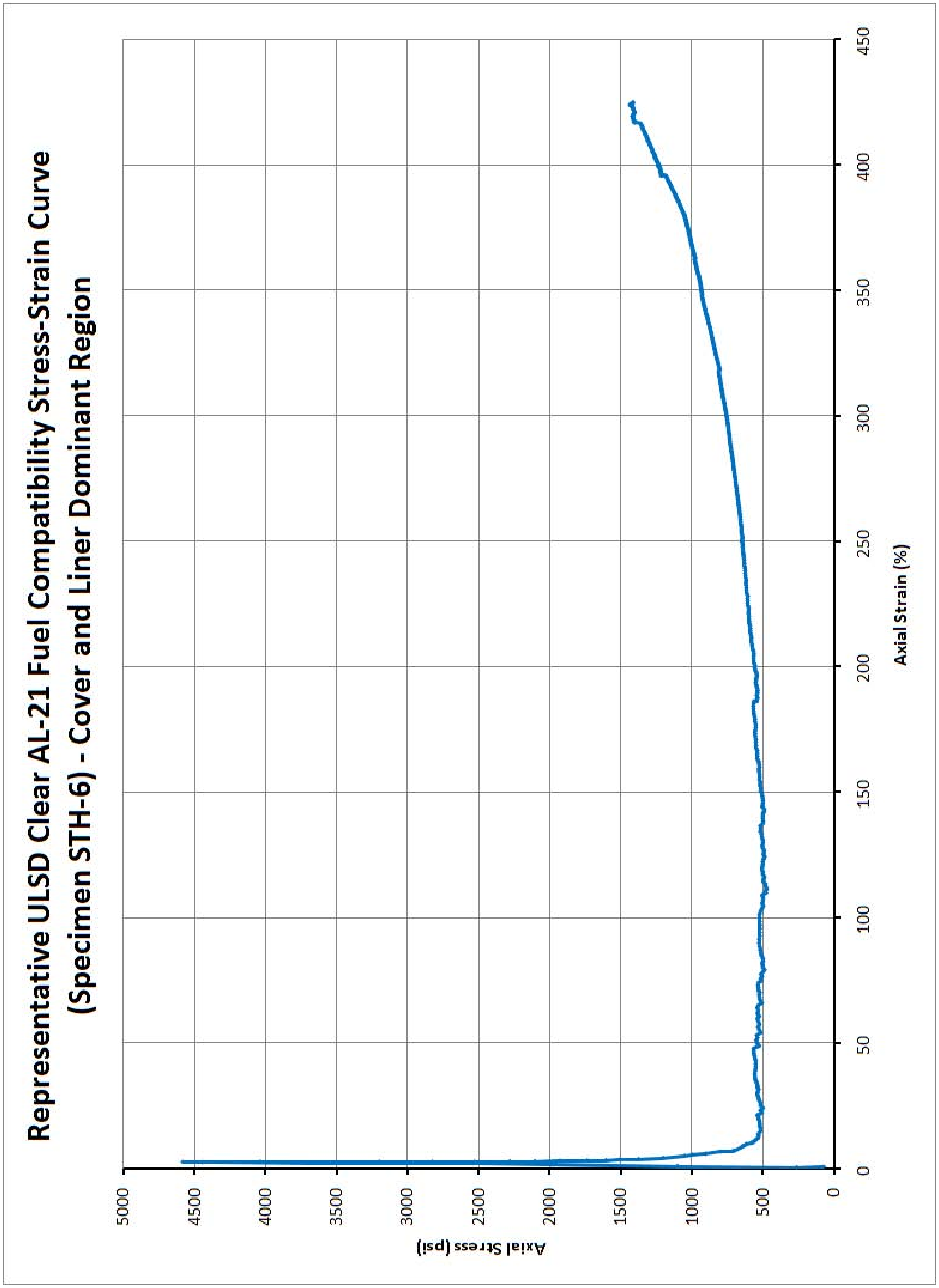
APPENDIX C

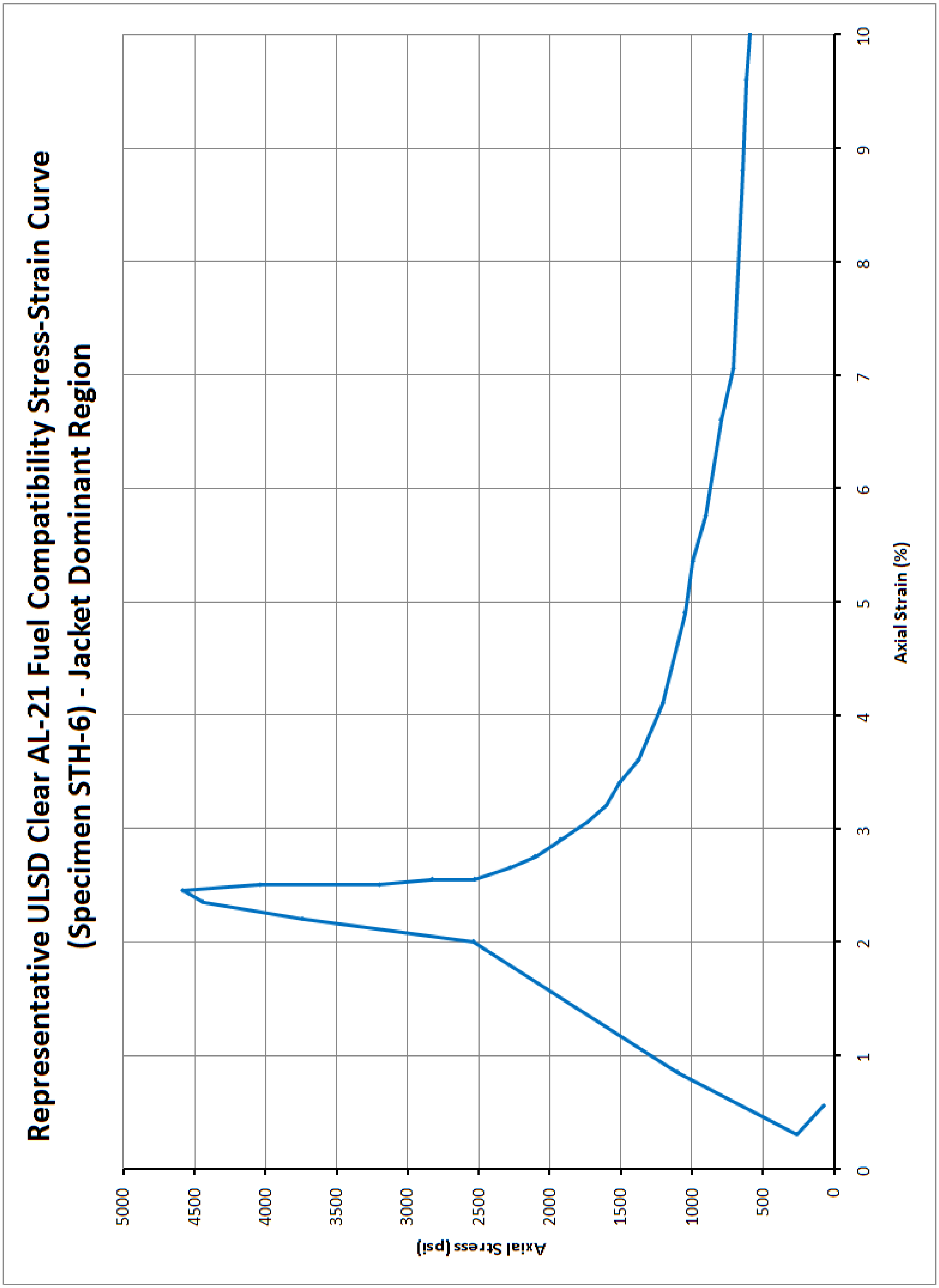
Graphs of Fuel Compatibility Tensile Test Data

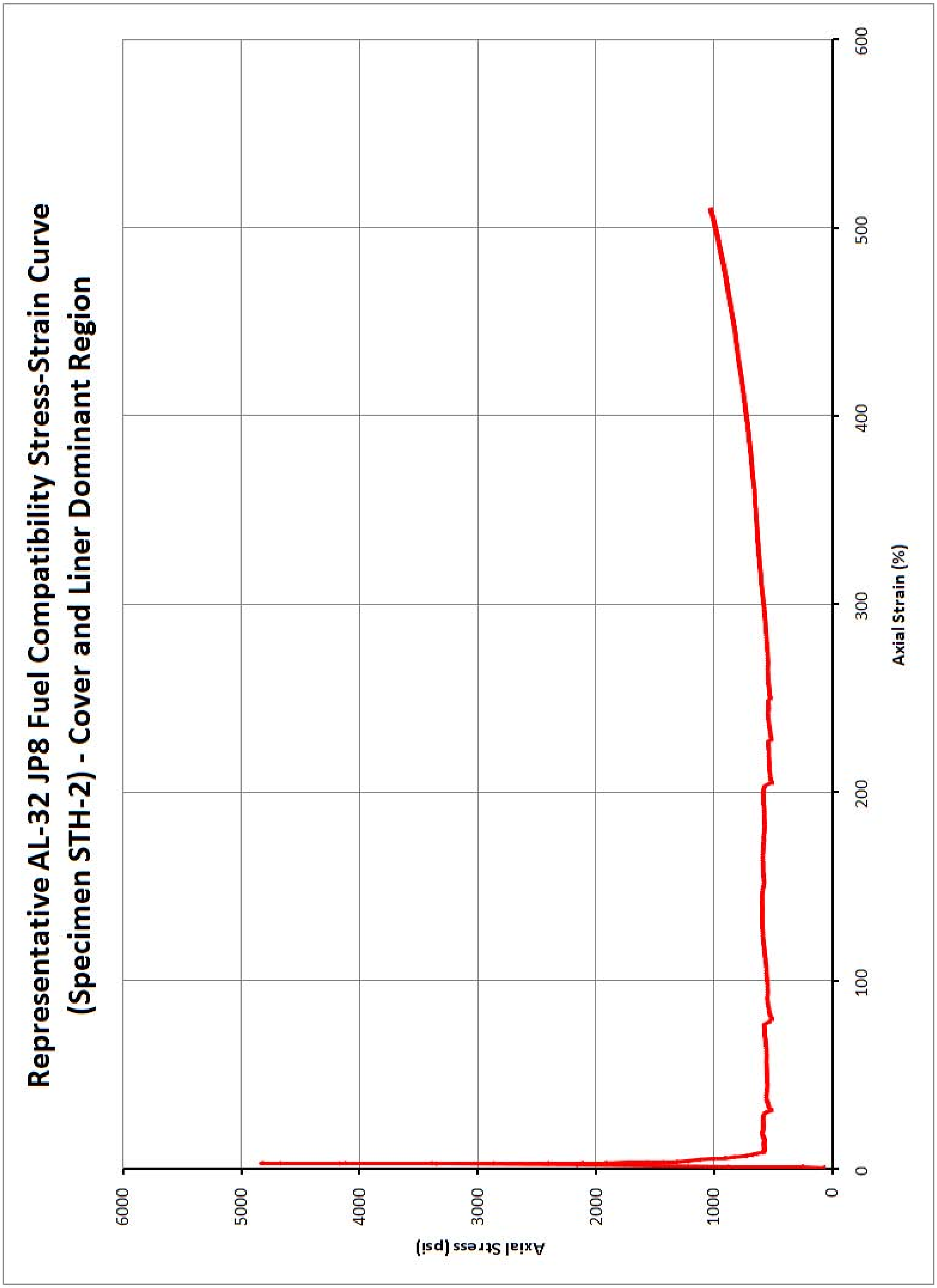

Representative Baseline Fuel Compatibility Stress-Strain Curve
(Specimen STH-11) - Cover and Liner Dominant Region
Axial Stress (psi)
0
1000
2000
3000
4000
5000
6000
Axial Strain (%)
0
100
200
300
400
500
600

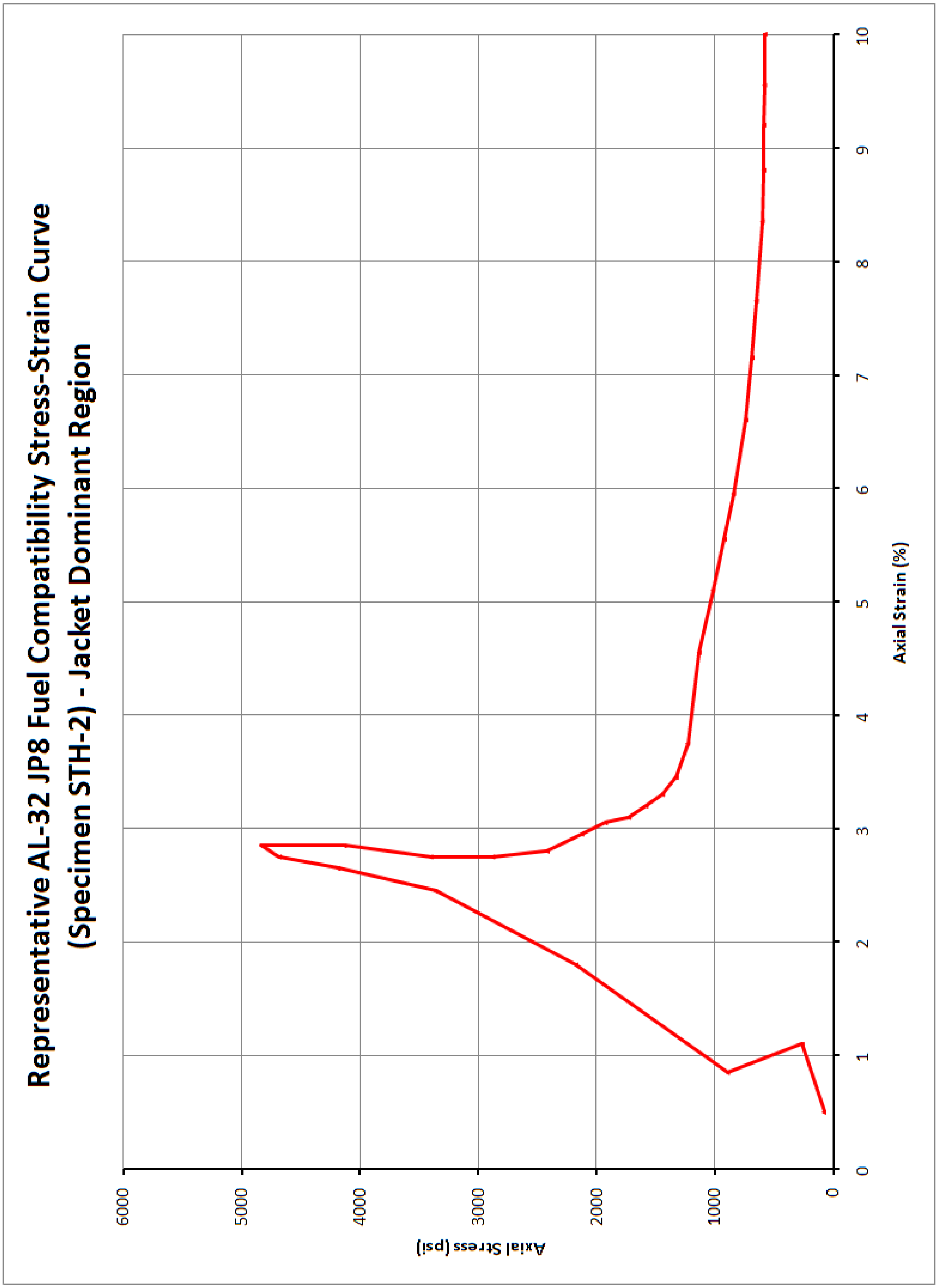

Representative Baseline Fuel Compatibility Stress-Strain Curve
(Specimen STH-11) - Jacket Dominant Region
Axial Stress (psi)
0
1000
2000
3000
4000
5000
6000
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10



Representative ULSD Clear AL-21 Fuel Compatibility Stress-Strain Curve
(Specimen STH-6) - Cover and Liner Dominant Region
Axial Stress (psi)
Axial Strain (%)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
50
100
150
200
250
300
350
400
450


Representative ULSD Clear AL-21 Fuel Compatibility Stress-Strain Curve
(Specimen STH-6) - Jacket Dominant Region
Axial Stress (psi)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10


Representative AL-32 JP8 Fuel Compatibility Stress-Strain Curve
(Specimen STH-2) - Cover and Liner Dominant Region
Axial Stress (psi)
Axial Strain (%)
0
1000
2000
3000
4000
5000
6000
0
100
200
300
400
500
600


Representative AL-32 JP8 Fuel Compatibility Stress-Strain Curve
(Specimen STH-2) - Jacket Dominant Region
Axial Stress (psi)
0
1000
2000
3000
4000
5000
6000
Axial Strain (%)
0
1
2
3
4
5
6
7
8
9
10